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Material Flow Analysis of Plastic Waste for Circular Economy Potential: A Case Study of Wijaya Kusuma and Sidomakmur Waste Banks in Metro City

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ABSTRACT

The volume of plastic waste in Metro City's landfill continues to rise, and by 2022, it is expected to reach capacity within two years. Waste banks are a crucial solution to reducing waste. This research aims to identify existing conditions, analyze the effectiveness of plastic waste reduction, assess the flow of waste materials, and measure the circular economy potential at the Wijaya Kusuma and Sidomakmur Waste Banks. Data were collected through interviews and observations and then analyzed using Material Flow Analysis (MFA), gap analysis, and descriptive analysis. The results show that the effectiveness of plastic waste reduction at the Wijaya Kusuma Waste Bank is 0.006%, and at the Sidomakmur Waste Bank is 0.007%. The STAN application facilitated MFA by integrating customer data through distribution. Based on circular economy potential, Wijaya Kusuma Waste Bank excels in value addition from plastic processing into plastic pellets. In contrast, Sidomakmur Waste Bank excels in managing waste volume and supporting processing facilities.

Introduction

Urban waste management remains one of the most pressing environmental issues in many Indonesian cities, with practical solutions still elusive in many areas (Naibaho, 2016; Yusuf, 2022). Among the existing waste streams, plastic waste is a particularly intractable problem due to its non-biodegradable nature and its widespread use in households, markets, offices, and public facilities (Suparyanto & Rosad, 2020). In response, handling plastic waste at its source is necessary for optimal waste reduction. One mechanism that is considered adequate in this regard is the establishment of waste banks (Iqbal & Suheri, 2019). Waste banks are beneficial in reducing the volume of waste entering landfills and providing economic benefits to their customers. One example is Bank Sampah Malang (BSM), which shows that waste banks play an important role in reducing waste and empowering the community's economy through recycling activities (Kurniawati, 2018).

One instrument to determine the effectiveness of waste banks in reducing plastic waste is to use Material Flow Analysis (MFA) so that the flow of materials entering the system can be quantified in both the flow of inputs, outputs and transformations (Brunner & Rechberger, 2017). In addition. MFA can be used to analyze material integration in circular economy models by minimizing waste generation and maximizing resource use efficiency by returning waste as input to a production process (Geissdoerfer et al., 2017). Thus, the value of the contribution made by waste banks can be measured in terms of the environment and the economy.

Metro City, as the second city in Lampung province, is not immune to the problem of plastic waste, where the composition of plastic waste reaches 24.07% of the total waste generation (SIPSN, 2023). The current waste management paradigm in Metro City still relies heavily on the final approach, namely sending waste to the Final Processing Site (TPA) in Karang Rejo. Until 2022, the volume of waste disposed to the landfill daily reached 220 m^3.

In response to this, the Metro City Government supports the establishment of waste banks at the urban village and sub-district levels, given the enormous economic potential that can be gained from waste management (Sukamto, 2022). Therefore, the Metro City Government will continue to support Bank Sampah Unit (BSU) in collecting waste from the source and Bank Sampah Induk (BSI) in converting waste into new products. In Metro City, two Parent Waste Banks manage plastic waste: the Wijaya Kusuma Parent Waste Bank and the Sidomakmur Parent Waste Bank.

Several previous studies have examined plastic waste management and the implementation of a circular economy through waste banks. For instance, Kurniawati (2018) found that the Malang Waste Bank successfully reduced waste volume and empowered the local economy through plastic recycling. Similarly, Aisyah et al. (2014) identified that processing plastic waste into plastic pellets in certain regions added significant economic value and helped reduce the burden on landfills.

However, this study differs from previous research by focusing on the Material Flow Analysis (MFA) of two central waste banks in Metro City, namely the Wijaya Kusuma and Sidomakmur Waste Banks. This research not only measures the effectiveness of plastic waste reduction but also assesses the circular economy potential of managed plastic waste, utilizing MFA techniques and the STAN application to map the material flow in greater detail. This study also provides a broader perspective on how waste bank technology and procedures can enhance the economic value of plastic waste.

This research is entitled "Material Flow Analysis of Plastic Waste for Circular Economy Potential: A Case Study of the Parent Waste Bank Wijaya Kusuma and Sidomakmur in Metro City." As the Main Waste Bank (BSI), BSI Wijaya Kusuma and Sidomakmur are downstream of the collection activities of the unit waste banks in Metro City. This study aims to evaluate the effectiveness of waste reduction using MFA and analyze the circular economic potential of the two waste bank units. This study investigated the circular economy potential of 3 recyclable plastic wastes, namely

Polyethylene Terephthalate (PET), Polyethylene of High Density (HDPE), and PP (Polypropylene).

Research Methods

This qualitative research was conducted at BSI Wijaya Kusuma and BSI Sidomakmur. The location was determined by direct observation and information obtained from government agencies, such as the Metro City Environmental Agency (DLH), regarding the activeness of the waste bank. This qualitative research uses literature study and field study data collection techniques. Literature study data collection is done by collecting data from relevant literature for this research. This research uses this literature study conceptually and methodologically as a reference and comparison. On the other hand, field studies were conducted using interviews and observations to obtain primary and secondary data.

To determine the percentage effectiveness of waste banks in reducing waste, data from Metro City's waste generation, plastic waste generation at BSI Wijaya Kusuma's waste generation, and plastic waste generation at BSI Sidomakmur must be compared. Measurement of effectiveness will use a percentage calculation with the following formula: (Kustanti et al., 2020)

$$\%Efek\text{tift}=\frac{\text{Managed waste generation}}{\text{Comparative waste generation}}x100\%\text{...}(3.1)$$

From the above calculations, data will be obtained:

1. Percentage of waste treatment in Metro City.
2. Percentage of waste reduction in Central Metro Sub-district.
3. Percentage of waste reduction in Metro Utara sub-district.

Then, this research analysis uses the Material Flow Analysis (MFA) method to review the material flow of plastic waste in waste banks and the effectiveness of waste banks. Analysis of the Circular Economic Potential of Plastic Waste in Waste Banks used the descriptive analysis method. The data analyzed were on plastic waste management procedures and the technology used by BSI. The procedure data was processed to complete the scope of the analysis of the circular economic potential of plastic waste in waste banks, as shown in Figure X.

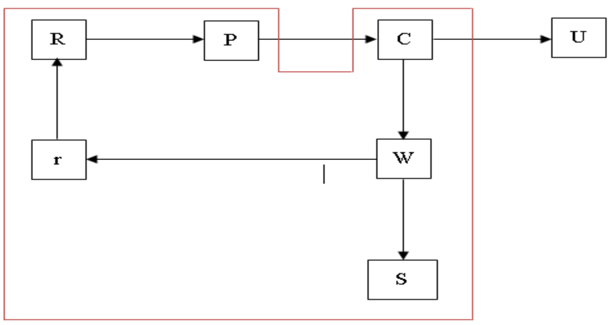

Figure 1. Scope of Circular Economy Potential Analysis at BSI Wijaya Kusuma and BSI Sidomakmur

Description:

C =Waste Bank customers
W = Total plastic waste entering BSI Wijaya Kusuma and BSI Sidomakmur
r = Recyclable plastic waste
R = Plastic waste that has the potential to become a resource
P = Plastic waste that has been processed into new products
S = Residue that has no economic value and will be disposed of back to the Metro City Landfill.

Unknown:

a. C $\longrightarrow$ W, to determine the total plastic waste entering BSI Wijaya Kusuma and BSI Sidomakmur.
b. W $\longrightarrow$ S, to determine the type and total plastic waste that cannot be recycled at BSI Wijaya Kusuma and BSI Sidomakmur and is directly disposed of at the Metro City Final Processing Site (TPAS). The S value is the residue expressed in kg/day.
c. W $\longrightarrow$ r, to determine the type and total plastic waste that can be recycled into raw materials at BSI Wijaya Kusuma and BSI Sidomakmur.
d. r $\longrightarrow$ R, by knowing the types of plastic waste that can be recycled (r), the total plastic waste that has the potential to become a resource (R) can be known. The following data needs to be known: a list of categories of plastic waste that can be recycled and the effectiveness of plastic waste that can potentially become new resources, such as raw materials for plastic seeds.

The categories of plastic waste that can be recycled as raw materials for plastic beans are polyethene terephthalate (PET), high-density polyethene (HDPE), and polypropylene (PP). Then, the plastic waste that has the potential to become a new resource is calculated with the following formula:

$$\%\ Effectiveness = \frac{\text{Managed PET waste generation}}{\text{The accumulation of PET waste entering the BSI}}\ x\ 100\% \quad \text{.......(3.2)}$$

$$\%\ Effectiveness = \frac{\text{The managed accumulation of HDPE waste}}{\text{The accumulation of HDPE waste entering the BSI}}\ x\ 100\% \quad \text{.......(3.3)}$$

$$\%\ Effectiveness = \frac{\text{The accumulation of managed PP waste}}{\text{The accumulation of PP waste entering the BSI}}\ x\ 100\% \quad \text{.......(3.4)}$$

e. R $\longrightarrow$ P, after knowing the total **plastic waste that has the potential to become a** resource (R), it can find out the total plastic waste that can be produced again in another form, and has economic value. It can be seen in units of kg/day.
f. P-value
After knowing the total **plastic waste that has been processed into new products** (P) in kg/day, the **economic value** can be calculated using the following formula:

P = mass x price of PET plastic waste
P = mass x price of HDPE plastic waste
P = mass x price of PP plastic waste

These data can be used to assess the circular economy potential of the two Parent Waste Banks based on their income levels.

Results and Discussion

Waste Management Procedures at the Parent Waste Bank

Waste management by recycling plastic waste through waste banks can be done to prevent and overcome environmental pollution or damage caused by waste (Muanifah & Cahyani, 2021). Based on the results of the interviews, customers at BSI Wijaya Kusuma and BSI Sidomakmur received education regarding waste management procedures. The waste deposited in the waste bank has been sorted (Abidin, 2023). Then the waste is received by the weighing officer and continued to the waste teller to be recorded in the savings book. What is recorded in the waste savings book is the weight of the waste that will later be sold by the manager to other industries, and the community will receive 100% of the sales proceeds. However, some customers supply waste in an unsorted state; this condition is still accepted by the waste bank manager, with the consequence that the price is lower than the one that has been sorted. In this study, the waste management procedure in the Metro City waste bank was obtained, as shown in Figure 2:

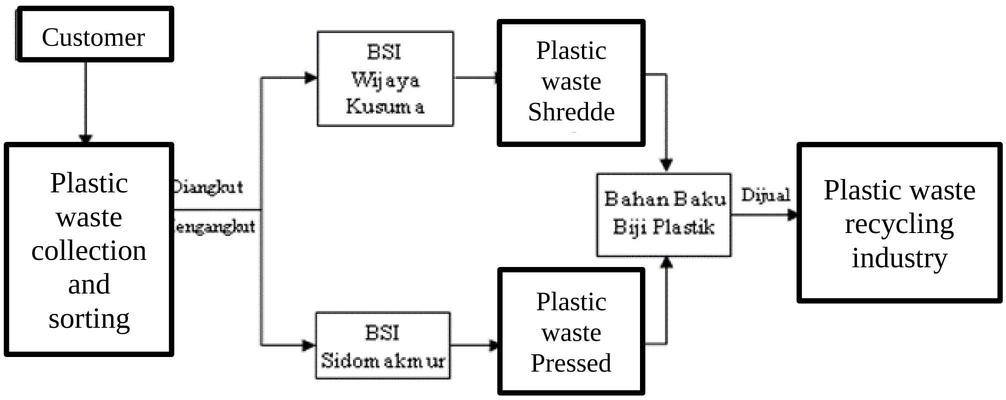

Figure 2.
Waste management procedure in Metro City waste bank

Material Flow of Plastic Waste in Waste Bank

Customer data and waste management procedures were used to create the MFA. Material Flow Analysis (MFA). In this research, the MFA was created using the Short for Substance Flow Analysis (STAN) application. Ideally, material flow has the same material input value as its output value (Brunner & Rechberger, 2017). Based on these data, the MFA results for BSI Wijaya Kusuma are diagrammed in Figure 3 and the MFA results for BSI Sidomakmur are diagrammed in Figure 4.

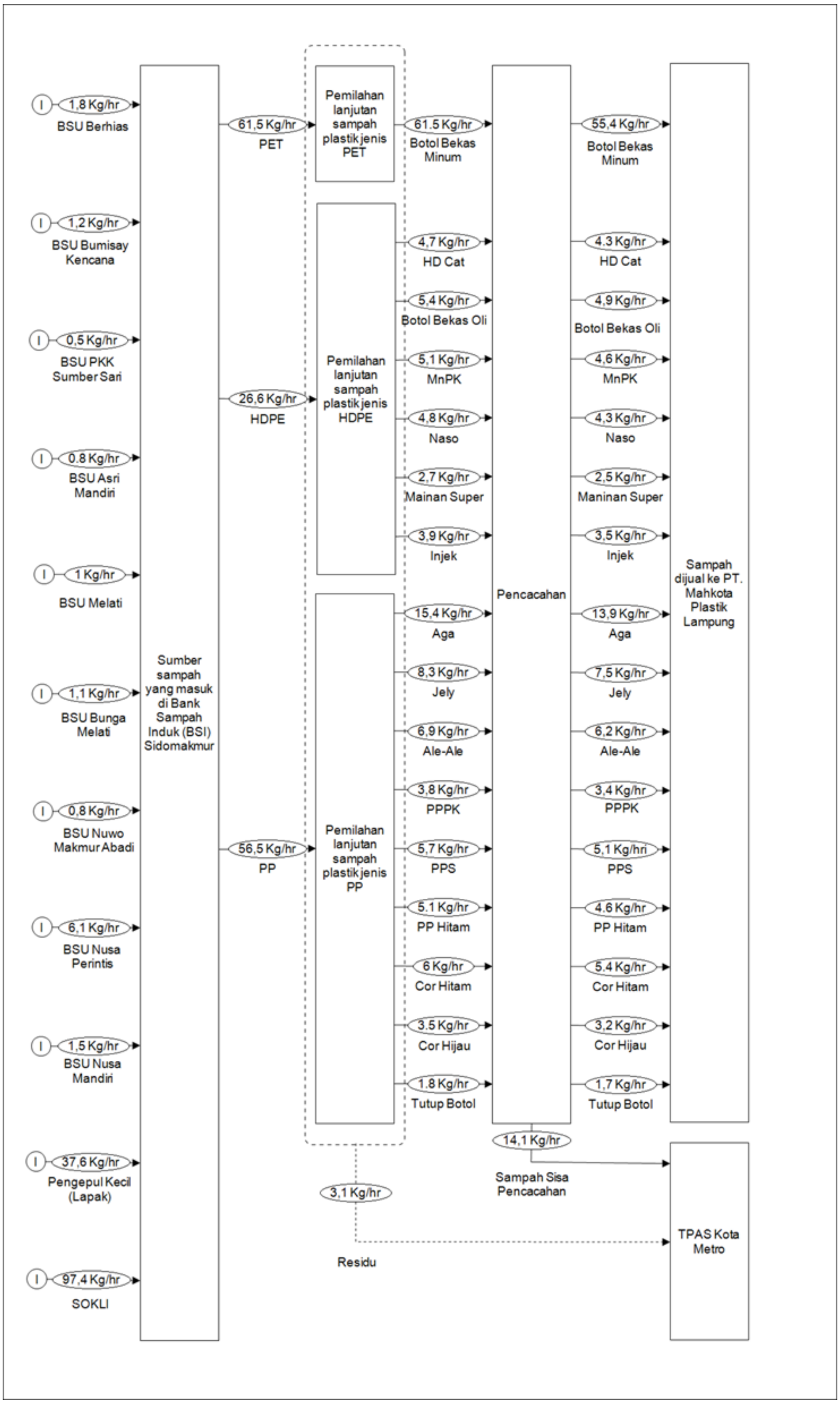

Figure 3.
Material Flow Analysis (MFA) at Wijaya Kusuma Main Waste Bank

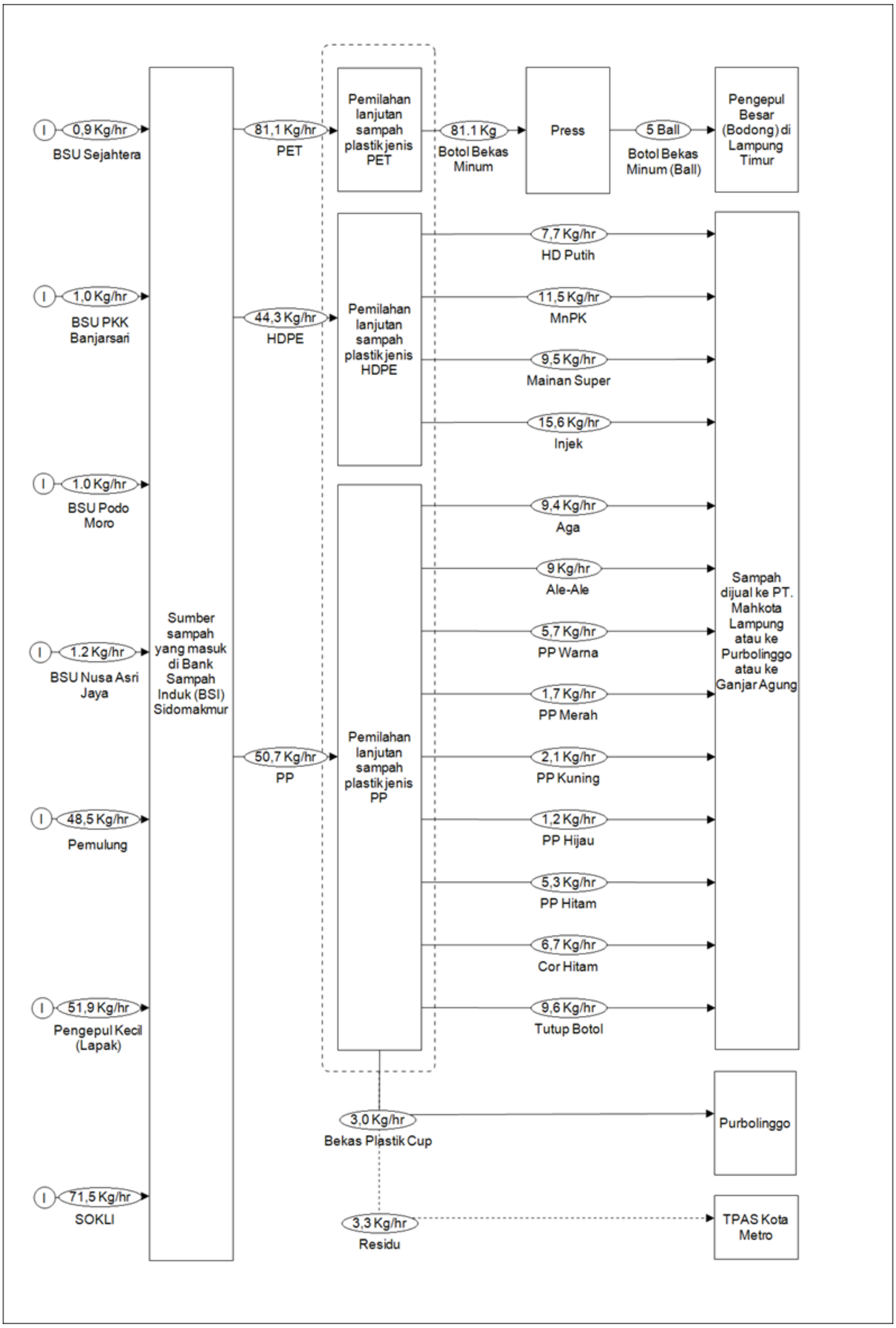

Figure 4.
Material Flow Analysis (MFA) at Sidomakmur Main Waste Bank

Based on Figure 3, it is known that the types of plastic waste that enter BSI Wijaya Kusuma are PET, HDPE, and PP. The sorting process produces 3.1 kg/day of residue and the shredding process produces 14.1 kg/day of unsalable residue. As for BSI Sidomakmur, the types of plastic received are PET, HDPE, and PP. Unlike BSI Wijaya

Kusama, BSI Sidomakmur does not have a shredder, so the residue and waste that cannot be pressed are 3kg/day and 3.3 kg/day, respectively.

Effectiveness of Plastic Waste Reduction

Waste reduction can be done by limiting waste production (reduce), reusing waste (reuse) and recycling waste (recycle) (Widarti et al., 2017). Although various measures to reduce waste (including plastic waste) have been practiced in waste banks in Metro City, their effectiveness still needs to be assessed (Tristy & Aminah, 2020). The effectiveness focuses on program outcomes, such as the waste bank development program in Metro City. The initiative implemented can be considered effective if the output achieved later matches the desired goal, namely the reduction of waste in the Metro City Landfill, especially non-biodegradable waste.

Table 1. Percentage Effectiveness of Plastic Waste Reduction

No.	Name of Waste Bank	Plastic Waste Input (Kg/day)	Untreated and Residual Amount (kg/day)	Effectiveness of Incoming Plastic Waste Reduction (%)	Effectiveness of Metro City Plastic Waste Reduction (%)
1.	BSI Wijaya Kusuma	**147,7**	17,2	88,4	0,52
2.	BSI Sidomakmur	**176,1**	6,3	96,4	0,68
Total BSI in Metro		**323,8**	**23,5**	**92,7**	**1,2**

Based on the data in the table, the effectiveness of reducing incoming waste at BSI Wijaya Kusuma and BSI Sidomakmur is 88.4% and 96.4%, respectively. This is because it has undergone cleaning and sorting at the BSU level. The Residue value comes from the non-BSU flow. Based on this value, BSI Wijaya Kusuma and BSI Sidomakmur have effectively processed the plastic waste that enters the waste bank. However, when viewed from the perspective of Metro City, the existence of these two waste bank centers can only handle 1.2% of the total plastic waste generated by its citizens. This is due to the fact that only 2 sub-districts out of Metro City's 5 sub-districts have waste bank centers and a limited number of customers at both the BSI and BSU levels.

Circular Economy Potential of Waste Bank

Based on the MFA results, the potential for circular economy planning can be identified. The potential value of the circular economy is assessed from the total waste generated by waste bank customers (W) to the stage of selling plastic waste that has become a new product (P).

Total Plastic Waste Generated by Customers (W)

Based on data from Table 1, the value of W entering BSI Wijaya Kusuma and BSI Sidomakmur is 147.7 kg/day and 176.1 kg/day, respectively. The total input of plastic waste generated at BSI Wijaya Kusuma and BSI Sidomakmur varies. One cause is the difference in the number of customers of each Waste Bank, and the amount of waste generated by each customer is different (Sholikah & Humurti, 2017).

Total Residual Waste Generated (S)

Waste generated in both BSIs (W) produces residue symbolized by "S. This waste is plastic waste that is not. The residue that enters BSI Wijaya Kusuma comes from waste sorting activities and is generated from the remaining plastic waste shredding will be disposed of to landfill amounting to details in Figure 3 17.2 kg/day, while based on field observations, residual waste at BSI Sidomakmur consists of a mixture of soil, water and garbage amounting to 3.3 Kg/day and used plastic cups as much as 3 Kg/day. In total, this amounts to 6.3 Kg/day. The water and soil residue will be disposed of in a landfill, while the used plastic cup residue, which usually has no selling value, is sold back to the grinder in Purbolinggo.

Percentage Effectiveness of Plastic Waste that Potentially becomes a New Resource (r) and (R)

Waste will have economic value if a circular economy is implemented. In the circular production process, "waste" is not placed at the end of the product life cycle but rather moved to the production regeneration process. Production regeneration can be carried out after it is known which types of plastic waste can be recycled (r), and then the plastic waste is produced back into new resources (R). Processing plastic waste into new resources is one of the efforts to recycle plastic waste into goods that are worth producing and trading again so that waste has economic value (Aisyah et al., 2014). After plastic waste becomes a new resource (R) in the form of plastic pellets, the total mass that can be sold to third parties (P) is calculated. Table 2 shows the percentage of new resource effectiveness at BSI Wijaya Kusuma and BSI Sidomakmur.

Table 2. Percentage Effectiveness of Plastic Waste Reduction

Plastic Waste Category	Total Plastic Waste Entering BSI (Kg/day) (r)	Total Plastic Waste Processed (R) (Kg/day)	Percentage of New Resources Effectiveness (%)
BSI Wijaya Kusuma - Enumeration to R			
PET	61,5	55,4	90
HDEP	26,6	24,2	91
PP	56,5	50,9	90
Total	**144,6**	**130,4**	**90**
BSI Sidomakmur - in Press (no R value)			
PET	81,1	81,1	100
Total	**81,1**	**81,1**	**100**

Processing Plastic Waste into New Resources (R)

Processing plastic waste into new resources is one of the efforts to recycle plastic waste into goods that are worth producing and trading again, so that waste has economic value (Aisyah et al., 2014). After plastic waste becomes a new resource (R) in the form of plastic pellets, the total mass that can be sold to third parties (P) is calculated. **The plastic waste processing method and the mass of plastic waste are different between the two BSIs.** BSI Wijaya Kusuma uses the method of shredding or grinding plastic waste. On the other hand, BSI Sidomakmur uses the plastic waste press method.

The technology used at BSI Wijaya Kusuma is a plastic waste-chopping machine. The machine works to crush, chop, and grind plastic waste into small sizes or what is known as plastic seeds (Darni et al., 2023). This processing is evidence that BSI Wijaya Kusuma has been able to implement the potential of the circular economy by converting plastic waste into new resources.

At BSI Sidomakmur, the plastic undergoes pressing; the pressing process is a process of separating the types of plastic waste, weighing, cleaning from brand labels and bottle caps, and then pressing (Jannah, 2019). Plastic waste that has been processed through a press machine cannot yet have the potential for a circular economy because the results of the pressing do not turn into new resources but only maximize the operational aspects of the waste bank. Therefore, the cycle only stops at point r, while the process of plastic becoming a new resource (R) is done by a 3rd party.

Analysis of Circular Economy Potential in Metro City Waste Bank

Figure 5 and Figure 6, respectively, show the scope of circular economy potential carried out by BSI Wijaya Kusuma and BSI Sidomakmur.

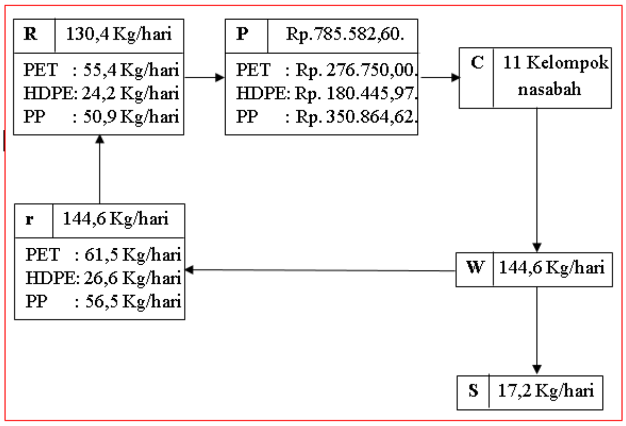

Figure 5.
Circular Economy Potential of Plastic Waste at BSI Wijaya Kusuma

The figure above shows the circular economy opportunities in BSI Wijaya, starting from the deposit of plastic waste by customers to BSI Wijaya Kusuma (C towards W). The waste bank manager again sorts the types of plastic waste that have potential economic value or not. If it has no economic value, it will be forwarded to the Metro City Landfill (W to S); otherwise, if it has the potential to have economic value, further sorting will be carried out (W to r) with recycling industry standards. Through the shredding method, plastic waste is transformed into plastic seeds (r to R). Finally, plastic waste that has been managed into a new resource is sold to the recycling industry (R to P), and the final result (P) is obtained with a total of Rp.785,582.60**.**

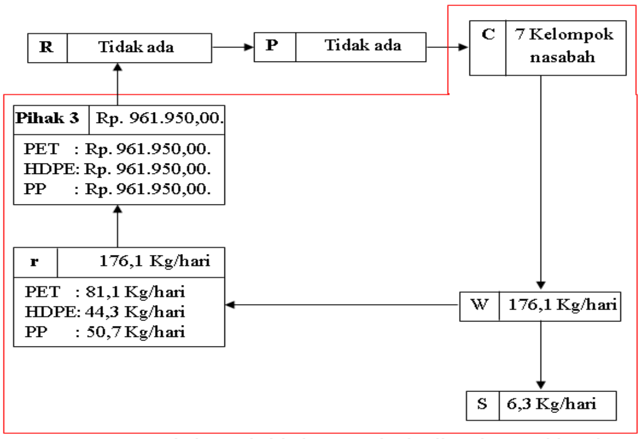

Figure 6.
Circular Economic Potential of Plastic Waste at BSI Wijaya Kusuma

The economic model at BSI Sidomakmur no longer uses the linear approach but still does not fulfill the circular approach because it only reaches (r). First, customers deposit waste at BSI Wijaya Kusuma (C to W). There are 3 (three) types of plastic waste deposited at BSI Sidomakmur with a large volume and potential to become a new resource (W towards r). After re-sorting, all three produce waste with no economic value or residue that is directly taken to the Metro City Landfill (W towards S). However, so far, BSI Sidomakmur has not managed to manage waste independently and turn plastic waste into new resources (R). This is due to the limited technology at BSI. The assessment results shown in Figure 6 indicate that BSI Sidomakmur is integrated into the wider waste management system, and the development of a circular economy requires the assistance of third parties.

Conclusion

Based on the results of this study, both BSIs have carried out waste management procedures for handling and processing waste. The MFA of both BSIs was analyzed by the customers who collected and sorted the waste and then deposited it into the BSI. Then, each BSI re-sorts and processes by shredding waste and compacting plastic waste until finally selling it to a third party. The MFA results become the reference for calculating the effectiveness of BSI in reducing plastic waste. At the waste bank level, the reduction of plastic waste has been effective, where BSI Wijaya Kusuma has an effectiveness of 88.4%, and BSI Sidomakmur reaches 96.4%. However, in terms of circular economy potential, only BSI has successfully implemented circular economy. Their plastic waste has been converted into new resources, such as plastic seeds, and sold to the industry. This means that BSI Wijaya Kusuma already fulfills the scope of circular economy potential from (C) to (P). On the other hand, BSI Sidokmakmur has not been able to implement a circular economy because the BSI's ability is only to the point (r). Plastic waste needs to be passed on to the next party in order to become a new resource (R). This causes BSI Sidomakmur to only fulfill the scope of circular economy potential from (C) to (r). Based on the results of this study, it is recommended that the Sidomakmur Waste

Bank invest in more advanced plastic processing technology, such as plastic shredders, to increase the economic value of managed plastic waste. Additionally, expanding the number of customers and waste bank units across Metro City is essential to enhance waste reduction's overall impact and alleviate the landfill's burden.

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