Development of an economically viable plastic recovery waste management system in Cibodas and Padamukti Village, West Java

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Abstract. Out of the 2,142 existing community-managed sorting and recycling facilities in Indonesia, known as TPS-3R, only 14% are functioning optimally due to economic challenges, highlighting the need for financially viable TPS-3R. To address this issue, the research aims to recommend an economically viable plastic recovery waste management system with optimum residue and income. Cibodas and Padamukti Villages are chosen as the case study location, as it has only 20% waste collection coverage and is located in the Citarum Watershed, whose river is a source of water for 60 million people and is part of the Citarik Ecotourism Living Lab. Primary data collection was carried out through interviews with recyclers in the villages and through waste volume and composition characterization. Three scenarios were developed for the Plastic Recovery Facility (PRF) objectives: Scenario 1 (S1) serves as the baseline of PRF, Scenario 2 (S2) buys plastic wastes from existing traders to be processed with more advanced plastic recycling technologies, and Scenario 3 (S3) is a self-sustaining PRF that could be replicated for the whole villages. Data analysis involved mass balance, financial models, BCR, NPV, and multicriteria decision-making. The residue disposed of in landfills is 32%, 17%, and 28% of the total waste managed for S1, S2, and S3. Financial modeling yielded BCR values of 1.06, 1.15, and 1.24, as well as NPV +IDR78,036,332; +IDR465,224,754; and +IDR354,414,072. The results highlight the importance of detailed analysis of mass balance and financial modeling according to the waste composition in any TPS-3R location, especially the differences in the value of rigid and flexible plastics, which will affect the types of technology and products. While the recommended scenario, S3, does not eliminate the need for capital investment from the government, it provides a framework to plan PRF with an operating surplus,

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which will increase the community's willingness to run it and ensure the PRF's long-term functionality to yield social and environmental benefits.

1 Introduction

Of the 6.8 million tonnes of plastic waste produced yearly in Indonesia, 61% are not collected and only 10% are recycled, resulting in pollution at sea, lakes, and rivers [1].

Indonesia's government has implemented 13,319 *Bank Sampah* (waste banks) [2] and 2,142 community-managed sorting and recycling facilities known as *Tempat Pengolahan Sampah* Reduce Reuse Recycle (TPS 3Rs) [3] to tackle this issue as an alternative to landfilling. Waste banks incentivize their customer for waste sorting at the source to induce behavior change [4] and TPS 3R promotes waste processing in the community to reduce waste-to-landfill [5]. However, the waste bank and TPS 3R have not offered a solution to the plastic waste problem because the Technical Guideline designed inorganic waste to be sold to recycling businesses [4, 5].

It is also important to note the types of plastic that are currently being recycled. Most recycling businesses in Indonesia only accept high-value materials such as rigid HDPE, rigid LDPE, PE, PP, PS, and PVC [6]. As a result, low-value plastics such as flexible PEs and multilayer packaging (MLP) are discarded and often contribute to environmental pollution through dumping and open incineration [1]. According to research by Waste4Change in 2022, 76% of plastic waste leaking into the environment in Indonesia consists of flexible plastics, with 33% being MLP of plastic and metal, 19% being MLP of various plastic types, and 48% of monolayer flexible plastics [6].

Apart from the gap between community-level plastic recovery facilities and the types of plastic being recycled, waste management facilities also face financial challenges that threaten their sustainability. According to the guideline, the waste bank's revenue from selling inorganic waste is to be divided into 85% for their customer and 15% for the waste bank management, which resulted in most of the employees working voluntarily [4] and the inability of the waste bank to cover operational expenses [7, 8]. TPS 3R has a similar trend of reliance on voluntary labor and government aid for capital and operational expenditure [9]. A case study in Central Java revealed only 14% of TPS 3Rs operate well [10]. This alarming situation necessitates urgent action to address Indonesia's waste crisis, particularly focusing on the economic challenges faced by existing waste management facilities.

To understand the drivers of economic sustainability for the Plastic Recovery Facility (PRF), we have chosen to conduct a case study in the villages of Cibodas and Padamukti in West Java, Indonesia which has similar experiences with waste management issues. These villages had been serviced by a TPS 3R and waste bank before they were abandoned [11]. They are located within the Citarum Watershed, an area previously identified as the most polluted river in the world [12, 13], where up to 23 pieces of waste per square meter have been recorded [14]. The 2022 study reported that out of 14,771 pieces of litter found in 6,000 m^2, 61% were plastic food wrappers (MLP) and 10% were plastic bags (flexible HDPE) [14].

This study aims to inform operational models for PRF that are financially viable and significantly reduce residual waste and waste leakage. Even though waste management services should be benefit-oriented instead of profit, achieving operational surplus while providing fair wages for workers is necessary to ensure its long-term continuity. Therefore, the scenarios in this study still need government capital investment, however, waste collection fees and product sales can cover the waste collection and plastic processing costs. This study presents 3 plastic processing technology scenarios that are evaluated against environmental and economic metrics. To address the types of plastic being recycled, this research explored a different value chain where the PRF collects household waste and processes plastic waste, while the organic waste is exported to organic recycling facilities elsewhere. In the scenario development and technology selection of this study, we will focus on putting flexible HDPE, flexible LDPE, and MLP into the value chain and processing them into a more high-value product. This inquiry includes a comparison of different processing technologies down to the level of suppliers to understand the technical and economical feasibility of PRF design. Because all recommendations are evaluated against the government-supported capital investment guidelines, TPS 3R design criteria, and community willingness to pay [5, 11], the research offers valuable insights for immediate implementation.

2 Methods

2.1 Scenario development

To explore the financial viability of a peri-urban Plastic Recovery Facility (PRF), this study models three different scenarios with various waste sources and compositions to find the most viable one (Table 1). Scenario 1 describes a similar-to-TPS 3R where waste collected is all types of waste from 400 households that pay the retribution fee. In Scenario 2, the PRF buys high-value plastics collected and separated by the local plastic traders to increase the number of waste processed in the facility, while incorporating more advanced technologies and producing higher-value products. In Scenario 3, we explored whether the PRF can produce the same types of high-value products as Scenario 2, without additional sources of plastic from the plastic traders.

Table 1. Differences of scenario 1, 2, and 3

	Scenario 1	**Scenario 2**	**Scenario 3**
Waste source	400 households (all types)	400 households (all types) & local plastic traders (PET, LDPE, HDPE, PP)	400 households (all types)
Waste collection	2 motor carts (2 m^3)	4 motor carts (2 m^3) & 1 pick up (6 m^3)	2 motor carts (2 m^3)
Processing machines	1 conveyor, 1 organic waste separator, 1 small trommel		
	1 plastic shredder	1 hydraulic press, 8 plastic shredders, 8 plastic injections, 2 plastic extruders	1 plastic shredder, 1 plastic injection, 1 plastic extruder
Types of Plastic Processed	**High value:** PET, rigid HDPE, rigid PP, rigid LDPE, **Low value:** flex. HDPE and LDPE	**High value:** PET, rigid HDPE, rigid PP, rigid LDPE, **Low value:** flex. HDPE, flex. LDPE, MLP	**High value:** PET, rigid HDPE, rigid PP, rigid LDPE, **Low value:** flex. HDPE, flex. LDPE, MLP
Products	**Raw materials:** separated and shredded waste	**Raw materials:** Pressed, separated, and shredded waste, **B2B product:** plastic beam, **B2C product:** coaster	**Raw materials:** Separated and shredded waste, **B2B product:** plastic beam, **B2C product:** coaster

In developing the scenarios presented in this study, we have taken into account local policies and constraints. We conducted interviews with five local plastic traders in Cibodas and Padamukti Village to understand the value of plastic waste per kg, the volume of waste collected, and the time-motion of the process. The survey revealed that most households on the site are willing to pay IDR 10,000/week for a once-a-week waste collection service [11].

2.2 Technology selection

When choosing waste processing technologies, we took into account various factors such as the availability of supplier information, technical specifications, the types of waste that can be processed, and initial investment and product pricing analyses. This analysis ensures that the selected technologies are readily available in Indonesia, increase the value of plastic types compared to other processing options, and include specific supplier names to facilitate the implementation of our recommendations.

Data collected from 24 waste processing suppliers in Indonesia includes the technology's dimension, processing capacity, types of waste processed, the energy needed, maximum operation hours, capital price and shipment price, and number of people needed to operate it. Based on available information, the following processing methods were considered for further analysis: sorting tables, conveyor belts, hydraulic presses, shredders, injection molding machines, and extrusion machines. Most TPS 3Rs use sorting tables, and the Technical Guideline of TPS 3R suggests a hydraulic press and shredder to process plastic waste before selling it to factories [5]. Therefore, conveyor belts, injection machines, and extrusion machines are considered advanced. A conveyor belt can increase the speed of waste sorting which is helpful for large waste volumes. Injection machines process shredded rigid plastic into small molded products, while extrusion machines can process rigid and flexible plastic into filaments or beams, depending on the size of the machine. The technical information of the machines combined with the price list of plastic waste products from the interviews are used to determine what kind of processing is the most beneficial for each type of plastic waste. For example, we decided PP cups are best processed as shredded rather than pressed or sold as is because it increases the value from IDR 6,000 per kg to IDR 12,000 per kg and the contribution margin of shredding PP cups outweighs the capital cost of buying a shredder. Lastly, we compared the machine and shipping price to determine which machine brands are more economical.

2.3 Material Flow Analysis: System definition and data acquisition

For each scenario, the process of material flow analysis involves tracking the amounts of waste that enter and exit the PRF through various stages including collection, processing, and sales. Data from the 2022 research in the location provides waste generation per capita of 0.532 kg/d, summing to an input of 622.44 kg/day to the PRF, 17% being plastic waste, and a detailed composition of the plastic types (Fig. 1).

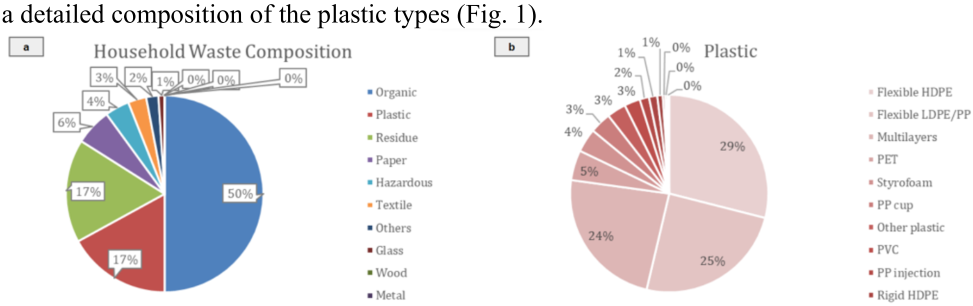

Fig. 1. (a) Household waste composition in Cibodas and Padamukti Village, where plastic is 17% of the total waste composition. (b) Plastic composition, detailed to the seven types of plastic and categorization of rigid and flexible plastic. The highest percentages are 29% flexible HDPE, 25% flexible LDPE/PP, and 24% MLP (2022).

According to the scenarios developed, waste from 400 households and/or plastic traders is collected with motor carts and/or a pick-up truck, followed by transportation to the PRF.

The first conveyor separates difficult-to-process waste such as diapers, textiles, wood, PVC, styrofoam, and other types of plastic. Glasses and papers are separated and immediately sold to recyclers. The separator machine is used to separate organics and flexible plastics, with the organics being processed into porridge and transported to the organic TPS 3R. The remaining flexible plastics are dry-cleaned using a small trommel, combined with rigid plastic, and processed on a second conveyor to separate them by plastic type and color. PET is pressed and sold for recycling, while rigid HDPE, rigid LDPE, PP cups, and PP injection are shredded or injected and sold. Non-rigid plastics such as flexible HDPE, flexible LDPE/PP, and MLP are turned into beams using extruders or sold directly for a lower price.

The three scenarios for waste processing yield different values and percentages of residue due to varying waste sources, volumes, and processing machines used. The scenario with the lowest percentage of residue is considered the best for the environment, while economic factors are also considered to ensure the chosen scenario is economically viable.

2.4 Financial modeling

2.4.1 Capital Expenditure (CAPEX)

The capital expenditure (CAPEX) of building a PRF consists of infrastructure and equipment. According to the regulation of TPS 3R, land used for public service is given free by the local community to the government as part of their contribution to the program [5]. To determine the size of the PRF area, detailed calculations are necessary as the amount of waste processed and the types of equipment used differ in each scenario. The area includes a parking lot for the motor cart and pick up, a waste input area, a vehicle maneuver area, enough space for equipment and staff movement, separate waste input and output areas for each piece of equipment, a storage room based on the waste volume for two days, a container for landfills, a dump truck maneuver area, a 2.5 m x 4 m office, and a portable toilet. In sum, PRF in scenario 1 is 110 m^2, scenario 2 is 232 m^2, and scenario 3 is 122 m^2. The construction fee of said PRF is estimated based on a reference from TPS 3R Kawasan Wisata Gunung Pring, Muntilan, Magelang, Jawa Tengah which resulted in a regression of IDR 2,410,000 per square meter [15]. All CAPEX is supported by government aid with a maximum of IDR 600 million. The scenario that exceeds this limit might need to search for additional funding.

2.4.2 Operating Expense (OPEX)

Operating expenses (OPEX) are the expenses incurred in running a business and generating revenue. OPEX is divided into two types: fixed and variable. Fixed costs are expenses that remain constant over a certain period because they are not affected by the quantity of goods produced, such as salaries for permanent employees and rent money. On the other hand, variable costs will always change in total according to the volume of waste processed. In this study, OPEX is calculated on an annual basis. Employee wages are calculated to adhere to the Bandung Regency minimum wage standard, with adjustments for 365 working days per year and 8 working hours per day. To address concerns related to functional sustainability, our fixed cost also took into account maintenance costs, which are estimated to be 5% of equipment CAPEX per year. The fixed cost also includes electricity for lights and water bills. The variable cost includes gasoline for the motor cart and pick up, electricity for the machines, and a retribution fee to the Department of Environment (DLH) with a rate of IDR 56,950 per m^3 of waste brought to landfill. For scenario 2, there is also an additional cost of purchasing plastic from the traders.

Table 2. Standard value of purchase and sales of waste in Cibodas and Padamukti (2022).

Plastic Type	Purchase Price	Shape	Selling Price
MLP	IDR 800/kg	Beams	IDR 3,250/kg
Flexible HDPE	IDR 800/kg	Beams	IDR 3,250/kg
Flexible LDPE	IDR 1,000/kg	Raw	IDR 1,700/kg
PP	IDR 2,500/kg	Shredded	IDR 12,000/kg
PET	IDR 3,000/kg	Raw / Pressed	IDR 4,800/kg
Rigid HDPE	IDR 3,500/kg	Shredded	IDR 10,000/kg
		Coaster	IDR 110,000/kg
Rigid LDPE	IDR 3,500/kg	Shredded	IDR 10,000/kg
		Coaster	IDR 110,000/kg

2.4.3 Revenue creation

The PRF generates income from waste collection retribution and from selling separated waste or processed products. Even though 400 households pay the same price of IDR 10,000 per week, the frequency of waste collection in all scenarios is increased from once a week to every two days which can reduce the number of waste disposed of in the environment or burned. To take into account the weight difference from wet to dry after the waste handling at the PRF, the volumes of waste counted in the sales are subtracted by 25%. The standard price of sales are listed in Table 2, with additional income from selling paper at IDR 2,850 and selling glass at IDR 500 per kilogram.

2.6 Net Present Value

We created models in Excel to input the CAPEX, OPEX, and revenue for each scenario. To evaluate the financial viability of each scenario, we projected cash flows for 5 years and discounted the cash flows at a 10% discount rate to determine the net present value (NPV) using Equation 1. A positive NPV means that the business opportunity is financially viable, while a negative NPV suggests that the business plan may not be feasible.

$$NPV = \sum_{n=1}^{t} \frac{Cash\ Flow_n}{(1+i)^n} - CC \tag{1}$$

2.6 Multicriteria Decision-Making (MCDM)

The assessment indicators in this multicriteria decision-making (MCDM) process consist of a combination of research control variables and the indicators and evaluation parameters of the 2017 TPS 3R Technical Guidelines [16], parameters from current practices of MCDM methods in sustainable engineering [17], and based on the study's objective.

Table 3. Aspects, indicators, weights, and value index used in the multicriteria decision-making for plastic recovery facilities based on the TPS 3R guidelines and practices in sustainable engineering.

Aspect	Indicators	Weights	Value Index	
Environmental	Waste Reduction	20%	2	<30% of the total waste received
			1	30-40% of the total waste received
			0	>40% of the total waste received

Aspect	Indicators	Weights	Value Index	
	Land Requirement	10%	2	<150 m^2
			1	150-200 m^2
			0	>200 m^2
Economical	Capital Cost	10%	2	<IDR 600 million
			1	IDR 600 - 800 million
			0	>IDR 800 million
	Operational Surplus	10%	2	>3 month's operational cost
			1	1-3 month's operational cost
			0	<1 month's operational cost
	Benefit Cost Ratio & Net Present Value	10%	2	BCR >1 and NPV positive
			1	BCR = 1 and NPV = 0
			0	BCR <1 and NPV negative
Technical	Types of plastic waste processed	10%	2	Rigid plastic and flexible plastic processed into products
			1	Rigid plastic processed into product, flexible plastic into raw material
			0	All types of plastic sold as raw material
	Waste Source Competition	10%	2	can be replicated without competition between TPS 3R
			1	no competition among TPS 3R, but competition between villages
			0	competition among TPS 3R
Social	Willingness to Pay	10%	2	less than WTP from the survey
			1	according to WTP from the survey
			0	more than WTP from survey
	Job Creation	5%	2	>4 employees
			1	3-4 employees
			0	1-2 employees
	Types of Product and Market	5%	2	Products for customers
			1	Products for local businesses
			0	Products for recycling factories

Indonesia's Ministry of Environment set a target of waste reduction under 30% by 2025 [18]. According to the TPS 3R Technical Guideline, the maximum area of TPS 3R is 200 m^2 and CAPEX of IDR 600 million [5]. The study aims to create a PRF that can sustain itself. However, the addition of a new source of high-value plastics to support the finance has scored lower in the Waste Source Competition (Table 3). This is because it means that another PRF in the same area may not receive the same financial boost, and as a result, may face economic challenges.

3 Results

3.1 Machines for the Plastic Recycling Facility

In the scenarios, the PRF will use machines to support the waste separation and treatment. After analyzing the cost and suitability with Cibodas and Padamukti's waste composition, the chosen machines are the Aneka Mesin conveyor, Cahaya Abadi Sakti waste separator, Tujuh Tujuh Teknik small trommel, PT. Trimas Nusantara hydraulic press, and shredder, injection, and extruder from Sumpah Sampah.

3.2 Material Flow Analysis (MFA)

Material flow analysis (MFA) diagrams were created to determine the percentage of residue generated that will be directed to the landfill. The analysis revealed that Scenario 1 produced 32% residue, Scenario 2 produced 17% residue, and Scenario 3 produced 28% residue.

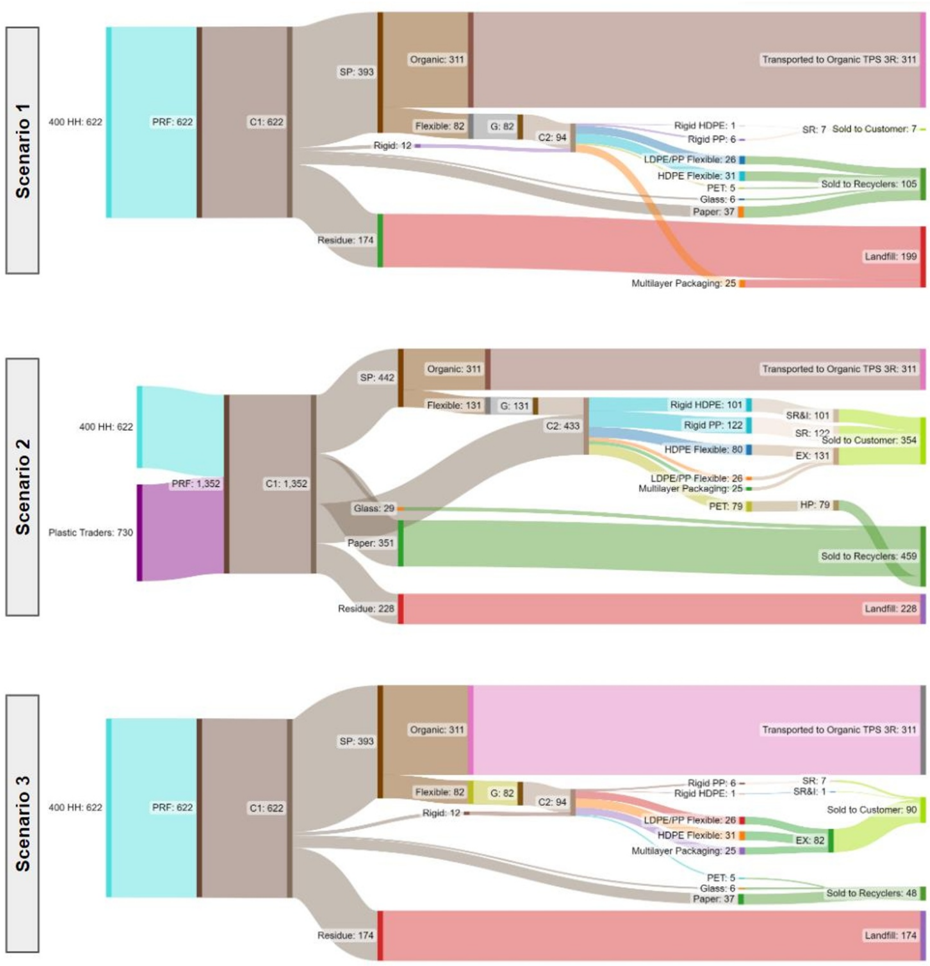

Fig. 2. Material Flow Analysis of Scenario 1, Scenario 2, and Scenario 3 in kg/d.

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3.3 Financial modeling and metrics

The CAPEX required for infrastructure and equipment is IDR 549 million, IDR 1,606 million, and IDR 691 million for S1, S2, and S3. As per the technical guideline of TPS 3R, the government is providing a CAPEX of up to IDR 600 million to support community-based organizations. Only Scenario 1 falls within this limit.

Operating costs are categorized into two types: fixed and variable costs. Fixed costs include employee wages, equipment maintenance, electricity for lighting, and water bills. Variable costs encompass gasoline, electricity for equipment, retribution, and waste purchasing (if any). The total fixed cost per year is IDR 248 million, IDR 636 million, and IDR 254 million for S1, S2, and S3. Meanwhile, the total yearly variable cost for S1, S2, and S3 is IDR 25 million, IDR 396 million, and IDR 37 million.

Revenue is generated from retribution fees and product sales. Retribution fees are the same for all three scenarios, which is IDR 208 million. This is because the number of households paying the fee is constant at 400 households, with each household paying IDR 10,000 per week. However, product sales (after deducting 25% to account for wet-to-dry weight differences) differ between the scenarios. Additionally, only 10% of the rigid HDPE and rigid LDPE for Scenario 2 are molded in the injection, with the rest being sold shredded. This is to prevent excessive inventory of coasters, which may be difficult to sell. Based on these sales, S1, S2, and S3 will generate IDR 86 million, IDR 1,202 million, and IDR 181 million per year. When compared to the yearly variable cost, the contribution margin for Scenarios 1, 2, and 3 are all positive.

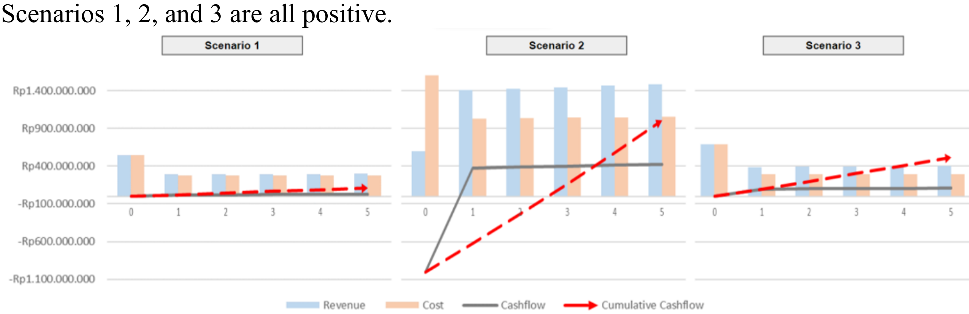

Fig. 3. Cashflow projection of Scenario 1, Scenario 2, and Scenario 3.

3.4 Result of Multicriteria Decision-Making (MCDM) for the PRF

Results of the parameters including waste residue, PRF size, capital cost, operational surplus, BCR, NPV, types of plastic waste processed, waste source, willingness to pay, number of employees, and types of the market evaluated against the MCDM values and weights, and then summed (Table 4). The MCDM scores of S1, S2, and S3 are 1.05, 1.30, and 1.75.

Table 4. Overview of results of the scenario analysis.

Indicators	Weights	S1	S2	S3	Justification
Waste reduction	20%	0	2	2	Waste residue = S1 32%, S2 17%, S3 28%
Land requirement	10%	2	0	2	PRF size = S1 110 m^2, S2 232 m^2, S3 122 m^2
Capital cost	10%	2	0	1	Capital cost (IDR) = S1 549 million, S2 1,606 million, S3 691 million
Operational surplus	10%	0	2	2	(Yearly revenue - Operating Cost) / Operating Cost = S1 0.92 month, S2 4.38 months, S3 4.07 months

Indicators	Weights	S1	S2	S3	Justification
BCR & NPV	10%	2	2	2	BCR = S1 1.06, S2 1.15, S3 1.24, NPV (IDR) = S1 +78 million, S2 +465 million, S3 +354 million
Types of plastic waste processed	10%	1	2	2	S1 produces raw materials only, while S2 and S3 produces products too
Waste source competition	10%	2	0	2	S1 and S3 is self-sufficient with the 400 household, while S2 takes additional high-value plastics from traders
Willingness to pay	10%	1	1	1	All scenario's retribution fee is the same to current WTP of IDR 10k/wk/HH
Job creation	5%	1	2	1	Employees = S1 4, S2 10, S3 4
Types of product and market	5%	0	2	2	S1 sells raw material to recycling businesses, while S2 and S3 have products for B2B and B2C
MCDM Score		**1.05**	**1.30**	**1.75**	**Scenario 3 is chosen**

4 Discussion

4.1 Waste pollution and recycling facilities

As mentioned in the introduction, there are two main parameters in reducing waste pollution to the environment which are ensuring waste collection sustainability and including flexible plastic in the value chain. There are three types of flexible plastic processed in this study: flexible HDPE, flexible LDPE, and MLP. Flexible HDPE and LDPE can be sold to recycling businesses, even though there is not a lot of flexible LDPE generated on the site. MLP is not economically viable to process with common methods because the layers are difficult to separate and the revenue won't cover the costs. However, the big extruder from Sumpah Sampah can process all three flexible plastics mentioned and turn them into plastic beams that can be sold to B2B as a building material. By putting them back into the value chain, we can reduce the residue in S1, S2, and S3 to 32%, 17%, and 28% respectively, which is already better than Indonesia's statistics of 47% open burning, 9% of leakage into water bodies, 9% dump sites, 5% dumping on land, and 20% managed disposal [1].

The success factors of Scenario 2 and Scenario 3 in reducing the residue percentage can be attributed to the increase of plastic processing machines and types of plastic treated in the PRF and Scenario 2 increase of high-value waste input. Apart from the pre-treatment machines, we can compare the contrast of Scenario 1 only has one type of machine and treats only three types of plastic, while Scenario 3 has three types of machines and treats six types of plastic. It can be concluded that to reduce waste pollution, recycling facilities have to be designed to collect and process more types of waste.

4.2 Challenges in developing an economically viable recycling facility

Through the financial modeling of the three scenarios, we can start to understand the drivers for an economically viable Plastic Recovery Facility (PRF).

Scenario 1 as the baseline of this PRF with a service area of 400 households and a minimum plastic waste processing similar to the TPS 3R Technical Guideline has a BCR of 1.06 and NPV of positive IDR 78 million and a high residue of 32%. In this scenario, the employees are paid ethically according to the minimum wage regulation in Bandung

Regency. However, with such minimum equipment and employees, the fixed income from the retribution fee can not cover the fixed cost of operations. This is why existing TPS 3Rs and waste banks in Indonesia, operate sufferably with government aid, manage voluntarily, and cannot cover operational costs [7, 8, 9, 10]. Waste management facilities need adequate funding from the government and also the beneficiaries, instead of demanding economic incentives from the recycling facilities like waste banks [4].

Scenario 2 involves positioning the PRF not only as a waste collection service for 400 households but also as a major trader of plastic traders in the village. The facility will process plastic waste into various products within the village, thereby making it an important player in the plastic recycling initiative. The result is a BCR of 1.15 and an NPV of positive IDR 465 million. Even though the economic performance of Scenario 2 is great with a yearly income of IDR 1,410 million and a margin of IDR 377 million per year, the CAPEX is more than 2.5 times the government aid, meaning the community has to search for additional funding like loans, which is difficult given that there is no guarantee they can pay it back. Additionally, the spike in income is caused by the additional waste collection from the plastic traders which are mostly high-value types of plastic such as PET, PP, and rigid HDPE. The additional source of waste will increase the competition between PRFs if this model is replicated within the same area. In Cibodas and Padamukti Village, there are over 7,000 households that require more than 15 PRFs. If high-value plastic is a source of economic viability for the facility, it will become a commodity of competition.

4.3 Plastic recycling facilities recommendation

The multi-criteria decision-making assessment in Table 4 revealed that Scenario 3 had the highest score of 1.75. Higher scores indicated a better scenario choice.

Recommendations according to Scenario 3 is to construct a 122 m^2 PRF with 25 light bulbs. Machines to procure include two 2-m^3 motor carts to collect wastes from 400 households; one conveyor belt, one waste separator, and one small trommel to separate and clean the wastes; one shredder, one injection machine, and one big extrusion machine to process the plastics into valuable products; and one waste container for the residue. 4 employees will spend 4.66 hours per day collecting waste [19], another 1.63 - 1.83 hours for the waste separation, and 0.24 - 1.63 hours for the waste processing.

Scenario 3 is better than Scenario 1 because it has more advanced technologies to process more types of waste, therefore reducing the residue transported to landfills. The land requirement is well within the 200 m^2 limit, but additional capital support is needed because it exceeds the government's aid of IDR 600 million. Scenario 3 is better than Scenario 2 because it achieves the waste reduction target, with good financial metrics of operational surplus, BCR, and NPV, without additional sources of high-value plastic, making it a self-sufficient solution.

5 Conclusion

The integration of mass flow analysis, financial modeling, and multi-criteria decision-making based on the waste composition, culminated in the development of a comprehensive model for the Plastic Recovery Facility (PRF) in Cibodas and Padamukti Villages. Taking into account the differences in the value of flexible and rigid plastics, all three scenarios for PRF exhibit economic viability with positive NPVs. However, when considering both minimizing landfill residues and the potential for replicating PRF across the village to serve all households, Scenario 3 emerges as the preferred choice.

The residual waste stands at 28% which is below the government's targeted limit of 30%. This figure highlights the need for reduced consumption of PVC, styrofoam, PS, PP straws, PP sacks, and other types of plastic if landfilling is to be reduced or avoided. The BCR stands at 1.24, and the NPV shows a positive IDR 354 million. The PRF facility occupies a space of 122 m^2, adhering to the TPS 3R technical guidelines' limit of 200 m^2. The initial CAPEX amounts to IDR 691 million, exceeding the maximum government aid by 15%, but it can be recovered in less than a year of operation. We suggest a government grant or loan to support the initial investment for a more economically viable PRF.

The technologies employed in the PRF include one Aneka Mesin conveyor, a Cahaya Abadi Sakti organic waste separator, a Tujuh Tujuh Teknik small trommel, plastic shredders, plastic injection machines, and plastic extruders from Sumpah Sampah. The machines are provided by suppliers based in Indonesia. The waste types processed encompass high-value plastics like PET, rigid HDPE, rigid LDPE, and rigid PP which will be turned into ball press, shreds, or coasters, as well as low-value plastics such as flexible HDPE, flexible LDPE, and MLP which will be turned into plastic beams.

With a uniform retribution fee of IDR 10,000 per week per household, the service area receives waste collection, separation, and processing services. This helps reduce the amount of waste polluting rivers, being incinerated, or ending up in landfills.

This study offers a framework for policy-making to design PRFs with operational surpluses, which would boost community support for running the PRFs and guarantee their long-term viability to produce positive social and environmental effects. The calculation of benefits from investing in processing equipment to convert plastic waste into valuable products can be the baseline for setting residue reduction targets. The developed technology selection and business model tool can assist in planning peri-urban's PRF, TPS 3R, and waste bank sizes, pricing, and technology choices to ensure operational break-even after the government's capital aid. Further empirical and theoretical research on different locations, waste compositions, and technologies will aid in the development of more sustainable waste management strategies in Indonesia.

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