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LIFE CYCLE ASSESSMENT AND COST BENEFIT ANALYSIS OF MUNICIPAL WASTE MANAGEMENT STRATEGIES

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Abstract

Cimahi City is located in West Java Province, Indonesia. With a population of half a million and the annual waste generation per capita reaching 0.48 kg/day, managing municipal waste has become increasingly challenging. To date, waste management costs in Cimahi City have not been specifically addressed. In addition to the total cost, there is also a plan to move the final landfill site from TPA Sarimukti, which is located approximately 34 km from the city center to a new final landfill site in TPA Legok Nangka, which is located approximately 56 km from Cimahi Municipality. This move will cause an increase in the cost to Cimahi Municipality. This study aims to analyze the optimum waste management strategies for Cimahi City according to the environmental and cost-benefit impacts of the landfill site move. We used life cycle assessment and cost-benefit analysis to determine the optimum solution for waste management strategies of Cimahi City. Four scenarios, including the addition of waste banks, were compared as municipal waste management strategies. The switch of landfills did not contribute significantly to the total CO₂ equivalent emitted. Increasing the number of waste banks could be an alternative to reducing the cost of waste disposal in landfills. Scenario (SC)-2 the scenario with additional government waste banks established, provided the highest net present value equal to Indonesian Rupiah (IDR) 1,428,622 per tonne of waste managed and was considered the most profitable in terms of the cost-benefit ratio. Hence, SC-2 was the most preferred for implementation in Cimahi City.

Keywords: Waste management; Waste Bank; Life cycle assessment; Cost-benefit analysis.

1. Introduction

Waste is one of the products of human activities that have an impact on the environment. Municipal waste is defined as waste collected or treated by or for municipalities. It domestic waste, such as bulky waste, as well as similar waste from commerce and trade, office buildings, institutions, and small enterprises, as well as yard and garden waste, street sweepings litter containers contents, and market cleansing waste if managed as household waste (OECD, 2021). Further, municipal solid waste (MSW) covers wastes from residential

areas including multifamily housing and waste from commercial and institutional locations, such as businesses, schools, and hospitals. (Schneider, 2017). Within the complexities of municipal solid waste management, the cost to handle the municipal waste is not small and increasing from time to time depending on the situation of every region. Waste management is a specific practice aimed at reducing the effects of waste materials on the environment and increasing material and energy recovery (Liu et al., 2017). Countries will likely always produce waste and they have to eliminate it in conjunction with their cultural context and the rate and way the society has approached modernity (Brown, 2015).

The city of Cimahi experiences an increase in population each year. In addition to the relatively small area, Cimahi has its charm, and because it is directly adjacent to Bandung City and Bandung Regency, it serves as an alternative strategic location. An infamous disaster due to the poor management of MSW was the landslide at the Leuwigajah dumpsite in 2005, in which 147 people lost their lives (Damanhuri, Handoko, & Padmi, 2014). Cimahi has a vision and mission of waste management, namely the innovative program “Cimahi Zero Waste City 2037.” This innovation implemented by the Cimahi City government aims to change the old paradigm of waste management in which waste is managed only by the government. The new paradigm, based on Law No. 8 of 2008, states that the community has a role in managing their waste at their respective sources. The foundation of the Cimahi City waste management policy in the medium term (2021–2025) is to strengthen the operational performance of the institutional and community-based waste management system to reduce waste by up to 50% at the waste source by the end of the medium term. Waste processing in Cimahi City began to shift to the Legok Nangka regional landfill at the beginning of the medium term. The limited land for waste disposal will cause an issue for the municipality shortly. Analysis regarding waste management needs to be conducted to optimizing the strategies for extending the age of landfill use for waste disposal.

Life cycle assessment (LCA) and cost-benefit analysis (CBA) can be used to analyze the effectiveness of waste management. In a previous LCA study in Macau, several likely scenarios were evaluated to explore the potential for reducing the environmental impacts of different MSW management strategies (Song, Wang, & Li, 2013). As part of the valuation method, CBA is a measurement method that aims to determine the value of the benefits of activity from an overall perspective. The CBA can be used as a tool to show the environmental benefits and costs that are usually not included in typical project analyses

(Dobraja, Barisa, & Rosa, 2016). The development of waste processing facilities in Pekanbaru was evaluated using CBA (Chaerul & Rahayu, 2019). In Bandar Lampung, CBA was used to determine efficiency in terms of economic costs as well as service areas and future developments to focus on planning in the solid waste sector (Phelia & Damanhuri, 2019). In Romania, cost analysis has been performed to analyze the best scenario for MSW (Ghinea & Gavrilesco, 2016).

Life cycle costing of waste management systems was used to propose a cost model that offers a coherent framework for assessing both the economic and environmental aspects of waste management systems by providing detailed cost calculations for individual waste technologies (Martinez-Sanchez, Kromann, & Astrup, 2015). According to a study in Medan City, solid waste recycling has the potential for recycling or composting of up to 91.69% of the waste generated from Medan City (Khair, Rachman, & Matsumoto, 2019a). Waste banks have also become a tool for bringing together stakeholders, including local government, public (communities), private sectors, non-government organizations, and mass media (Wijayanti & Suryani, 2015). Based on a previous study, Cimahi waste banks have the potential to manage waste up to 50% of total waste disposal (Putri & Sembiring, 2018). An economic analysis conducted by previous research in Cimahi city concluded that waste management by waste banks is beneficial for all parties, including the government (Syamsu, 2017).

The environmental and cost assessment of municipal waste management in Cimahi City needs to be more explored. According to the previous study using LCA and CBA methods to determine the optimum solution of waste management, this study investigated the moving landfill site and waste bank employing those methods to support the vision of Cimahi City regarding municipal waste management strategies. This study aimed to analyze the environmental assessment and cost-benefit impact from the move of the landfill site from TPA Sarimukti, which is located approximately 34 km from the city center to a new landfill site in TPA Legok Nangka, which is located approximately 56 km from Cimahi City. The moving of the landfill site will cause an increase in costs. In addition, the impact of the addition of waste banks to the management of municipal waste in Cimahi City was investigated.

2. Methods

2.1. Study location overview

Cimahi is one of the supporting cities in West Java, as it is located near the center of activity of the capital West Java Province, Bandung City. Cimahi is about 20 kilometers from the center of Bandung City. North Cimahi, Central Cimahi, and South Cimahi are the three districts that make up Cimahi. Cimahi has an area of 40.37 km² and a population of 554,755.

Based on the data from the environmental agency of Cimahi Municipality, the average waste generated in Cimahi per capita is 0.486 kg/day (DIKPLHD Kota Cimahi, 2018). According to the data, about half of the waste generated in Cimahi is organic waste, followed by plastic waste. Generally, the waste management method in Cimahi city is divided into two primary methods based on the type of waste. For organic waste, treatments used are composting and Waste-to-energy. Inorganic waste is treated using TPS 3R and Waste Bank. Composting in a centralized plant has the highest potential for success in handling wastes from traditional markets in cities of Indonesia (Aye & Widjaya, 2006). The mass flow diagram of the waste in Cimahi City is presented in Figure 1. The data used in this diagram are adapted from the annual report of the Environmental Agency of the Cimahi Municipality (DIKPLHD Kota Cimahi, 2018).

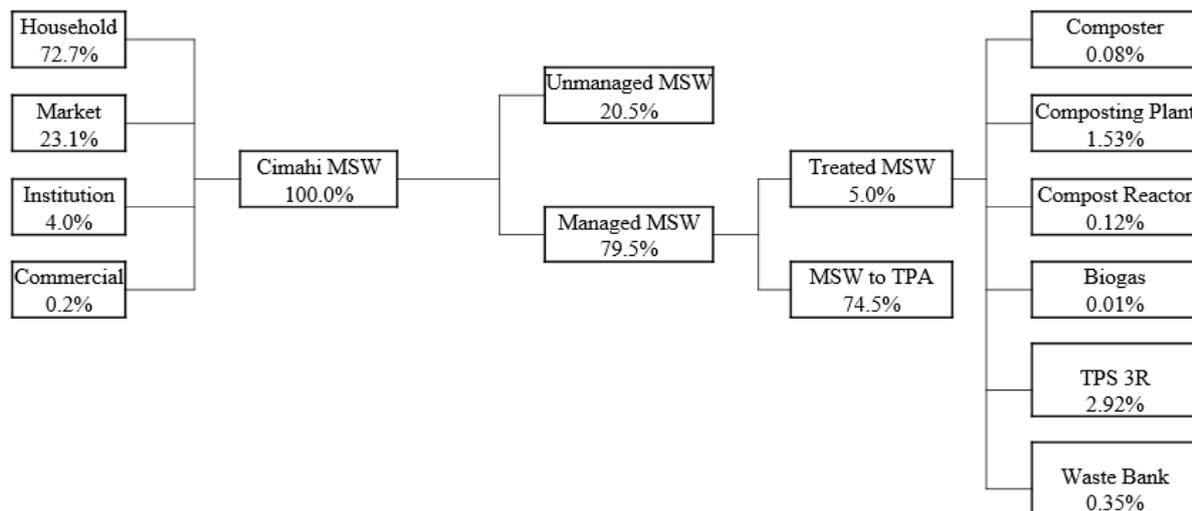


Figure 1. Mass flow diagram for waste in Cimahi City

Facilities developed to reduce inorganic waste disposal to the final landfill consist of TPS 3R and Waste Bank. One of the community-based waste management solutions, the waste bank, allows the public to actively participate in environmental management (Wijayanti & Suryani, 2015). Combining the application of waste bank and 3R-transfer station is also DOI: <https://doi.org/10.7454/jessd.v4i1.1107>

good for the environment especially in reducing greenhouse gas emission (Raharjo et al., 2016). The way waste bank enables public is by giving them financial stimulus from monetizing their waste. Currently, there are 63 waste banks spread through all of Cimahi city.

In Cimahi, there is only one central waste bank with an average capacity is 356.09 tonnes/year; the rest of the waste bank is a subsidiary of the central waste bank with an average capacity is 119.90 tonnes/year. All subsidiary waste banks will send their waste to Cimahi central waste bank. Thus, gateways of selling recyclable products are done only via the central waste bank.

Until 2019, waste from Cimahi city, Bandung metropolitan area, and several regions close by areas brought their waste to a regional landfill named TPA Sarimukti, which is located 23 km away from the center of Cimahi city. TPA Sarimukti has an area of 25.2 ha and has been operating since May 28th 2006. Due to the contract on landfilling in TPA Sarimukti is finished by 2020, Cimahi has to discharge the waste to another landfill. Currently, Cimahi did not have its landfill. Thus, people need to transport the waste to province-owned new landfill site, TPA Legok Nangka. Map of TPA Sarimukti, Cimahi City, and TPA Legok Nangka is shown in Figure 2.

2.2. Life Cycle Assessment

Life Cycle Assessment (LCA) is a method to determine the effects of a process or series of processes in producing products to the environment. The limitations of the process assessed should be first defined, then using the LCA method the impacts could be inferred. The first and mandatory step consists of assessing the sensitivities of the LCA results to all main assumptions by scenario analysis (Laurent et al., 2014). According to ISO 14040:1997/2006, there are four steps to conduct LCA, goal and scope definition, Life-cycle inventory (LCI), Life-cycle Impact Assessment (LCIA), and interpretation (International Organization for Standardization, 2006). Efforts to synchronize LCA with the economic value of projects are also done in various research.

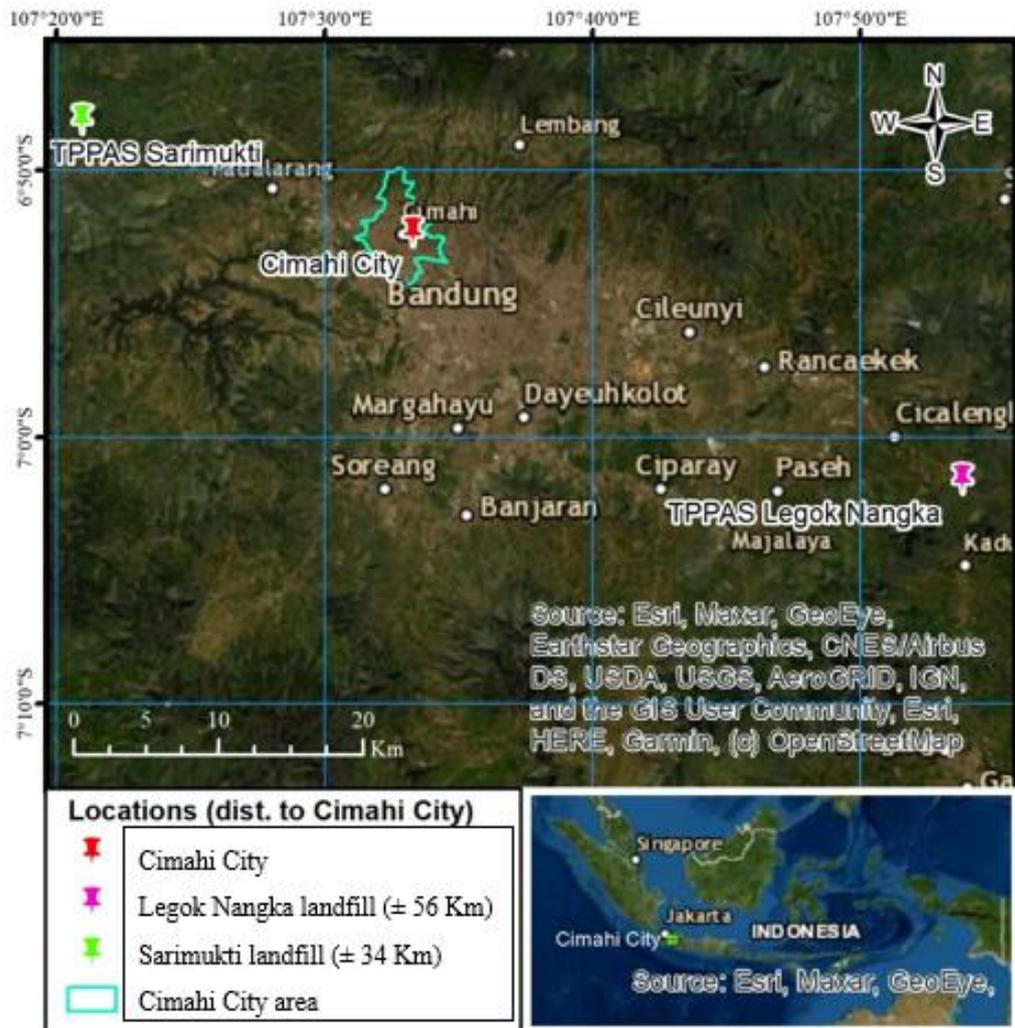


Figure 2. Map of Cimahi City among Sarimukti landfill and Legok Nangka landfill

The results of the collected and estimated inventory data were categorized. In this study, the emissions considered were CO₂, CH₄, and N₂O. Avoided landfilling consisted of inorganic materials that were sold by the waste bank to the recycling industry. These inorganic materials have the potential to reduce the use of raw materials in the respective industries. The calculation of these emissions used the waste reduction model (WARM), which also adopts LCA methodologies (US EPA, 2020). The emission factors used in this study for CO₂, CH₄, and N₂O were obtained from the Intergovernmental Panel on Climate Change (IPCC). The environmental effects from collection and transportation were estimated based on fuel consumption, the number of vehicles used, and the distance traveled. The general equation used to estimate the emissions was adopted from the IPCC (IPCC, 2006).

The boundary of the study is from the collection phase of waste until the final treatment of municipal waste.

$$E = \Sigma Fuel \times EF \quad (1)$$

E = emission (kg), Fuel = fuel consumed (TJ), EF = emission factor (kg/TJ).

2.3. Cost-benefit analysis

The costs and benefits of the management scheme should be considered to evaluate the economic aspects of municipal waste management in Cimahi City. Subsequently, we can compare and decide which waste management scheme is profitable and suitable for Cimahi. CBA was used in this study to determine the value of the benefits of activity from an overall perspective. According to Hylton (2016), the total cost and benefit of projects are defined in two components presented in the following equation:

$$Total\ Benefit = B\ internal + B\ external \quad (2)$$

$$Total\ Cost = C\ internal + C\ external$$

An internal benefit included in this study was the retribution fee from waste management for every resident in Cimahi. Other internal benefits are realized from selling the recovered items collected by the waste bank. From the waste treatment process, waste collection and transportation produce emissions, which indirectly harm the environment and could be considered as external costs. In contrast, the avoided use of raw material because of the use of recovered material resulted in less CO₂ emitted owing to the material collecting process. This process is an external benefit. Externality should be converted to a comparable value to understand the external costs and benefits resulting from those actions. To convert those externalities, this study employed the social cost of carbon (SCC) to monetize CO₂. External cost and benefit in this study are estimated using an SCC value of 37 USD per tonne CO₂ or Indonesian Rupiah (IDR) 539,534 per tonne at a 3% discount rate. The functional unit used for environmental assessment is CO₂ equivalent (CO_{2e}) per tonne waste managed and will be hypothetically monetized using Social Carbon Cost (SCC) Conversion Factor. Functional unit for cost analysis is Rupiah per tonne of waste managed. The detailed cost-benefit component shows in Table 1.

Table 1. Cost component and benefit component

Type	Component	Code
Cost component		
Direct cost (internal)	Collection	C1
	Transfer point	C2
	Transportation	C3
	Landfilling	C4
	Government supported waste bank operational cost	C5
	Cost of buying waste	C6
	Private waste bank operational cost	C7
Indirect cost (external)	Collection (emission)	C8
	Transportation (emission)	C9
	Environmental (emission)	C10
Benefit component		
Direct benefit (internal)	Retribution fee	B1
	Selling from government waste bank	B2
	Selling from private waste bank	B3
Indirect benefit	Environmental (emission)	B4

Cost component analysis is performed by adding up the cost values of a scenario such that the total cost (net cost) of each planned scenario is obtained. Benefit component analysis is performed by adding the benefit values of each scenario to obtain the total benefit (net benefit). Based on Table 1, the net cost and net benefit equations are:

$$Net\ cost = C1 + C2 + C3 + C4 + C5 + C6 + C7 + C8 + C9 + C10 \quad (3)$$

$$Net\ benefit = B1 + B2 + B3 + B4$$

3. Results and Discussions

3.1. Municipal waste management scenario

Data used in these scenarios are provided by the environmental agency and central waste bank of Cimahi City. Due to the limitation of availability of data, this study also adapted some data from previous research conducted in Cimahi City and from cities that conducted a study about CBA in the waste bank, in this case, the researchers involved Pekanbaru waste

bank for waste bank operational cost. All the scenarios below are using similar set of databases, which is 2018 waste generated. The component and compositions of the managed waste are presented in Table 2.

Table 2. Composition of managed waste

Component	Composition	Weight (tonne/year)
Organic	48.06%	52,507.5
Paper	8.58%	9,374.0
Plastic	16.18%	17,677.3
Steel	3.46%	3,780.2
Glass	3.42%	3,736.5
Fabric	5.92%	6,467.8
B3	1.34%	1,464.0
Others	13.04%	14,246.7
Total	100.00%	109,254

The collection phase included every method of collecting waste from the waste source all over Cimahi City. The first collection phase was collecting waste in concrete garbage bins around residences and bringing these to temporary transfer points. This phase also included transferring the waste from subsidiary waste banks or smaller waste banks to the central waste bank. Transfer points aggregated waste from various sources, primarily from households. The waste was stored temporarily until the container was full and then transported to the final landfill using an arm-roll truck. Waste from the transfer points was then brought to the final landfill site using two types of trucks.

The first was an arm-roll truck, mentioned previously. This type of truck can hold different amounts of waste depending on the volume of the container. The second type was dump trucks that were used to collect waste from institutions, commercial areas, and markets. Dump trucks were also of different types depending on their capacity. Waste collected by waste banks was then aggregated in the central waste bank, where it would be sold to recycling industries. These industries came to the central waste bank and then collected the waste material themselves. These aggregated inorganic wastes are used as

substitutes for raw materials. For example, used plastics could be reused as materials for new plastic products instead of being made into plastic pellets.

The current landfill to which the waste from Cimahi City is disposed of is not municipally owned but is private or province owned. Therefore, the Cimahi government has to pay a landfill fee for each tonne of waste disposal. For the Sarimukti landfill, the landfilling fee is IDR 50,000 per tonne, whereas for the Legoknangka landfill, the landfilling fee is IDR 270,200 per tonne of waste. Landfilling fees at the Legoknangka landfill were IDR 500,000 per tonne after negotiating with the Governor. The city received subsidies and had to pay only IDR 270,300 per tonne of waste.

The anticipated environmental impacts depend on several factors such as characteristics and composition of waste, the efficiency of the waste collection, and the processing systems required by different waste management practices (Elagroudy, Elkady, & Ghobrial, 2011). In this study, we conducted four scenarios to assess the waste management strategies of Cimahi City.

A. Scenario 0 (existing condition/SC-0)

In the SC-0 scheme, the landfill site is still in the Sarimukti landfill. The proportion and capacity of waste management were calculated on a wet weight waste basis, which is the proportion that was used in the 2018 government database. The waste bank used in this scenario is similar to the previously explained process of waste treatment in Cimahi City. The waste bank capacity in this scenario is 0.35% of the total waste generated annually in the Cimahi municipality, with 1 government or central waste bank and 62 subsidiary waste banks that are centrally managed by the government waste bank. This scenario was evaluated to determine potential differences between scenarios.

B. Scenario 1 (SC-1)

SC-1 was similar to that of SC-0 except that a new landfill, TPA Legok Nangka, was used in this scenario.

C. Scenario 2 (SC-2)

In SC-2, new waste banks were established that together accounted for a total of 3% of the treated waste or equal to 10 government waste banks as an alternative means to reduce

inorganic waste disposal to the landfills. In this scenario, these newly established waste banks are subsidiaries of government-supported waste banks. These waste banks are established under local government policy; therefore, the waste is collected and treated in a manner similar to that at the previously established waste bank. Inorganic waste is separated by residents and brought to the waste bank. After the waste is sold, the money is deposited into each of the residents' bank accounts. The money from selling recovered items is managed by the central waste bank unless the resident collects it from their account. As a subsidiary, the newly established waste bank becomes a place that only receives waste, and all financial management responsibility is borne by the central waste bank.

D. Scenario 3 (SC-3)

The SC-3 scheme had a solution similar to that of SC-2, the establishment of 10 new waste banks, with some modifications. The difference is who supports the waste banks. In SC-2, the waste banks are supported by the government. In SC-3, the newly established waste banks are based on residents' initiatives or private waste banks, which implies they are not subsidiaries of the central waste bank. These waste banks operate on their own, and therefore, financial management responsibilities are borne by the residents themselves. Establishing these 10 new waste banks equals redirecting 2.66% of the total waste generated from direct disposal to recycling industries, where if added to the established waste banks will total to approximately 3% of the total waste treated. The waste flow in all the scenarios is shown in Figure 3.

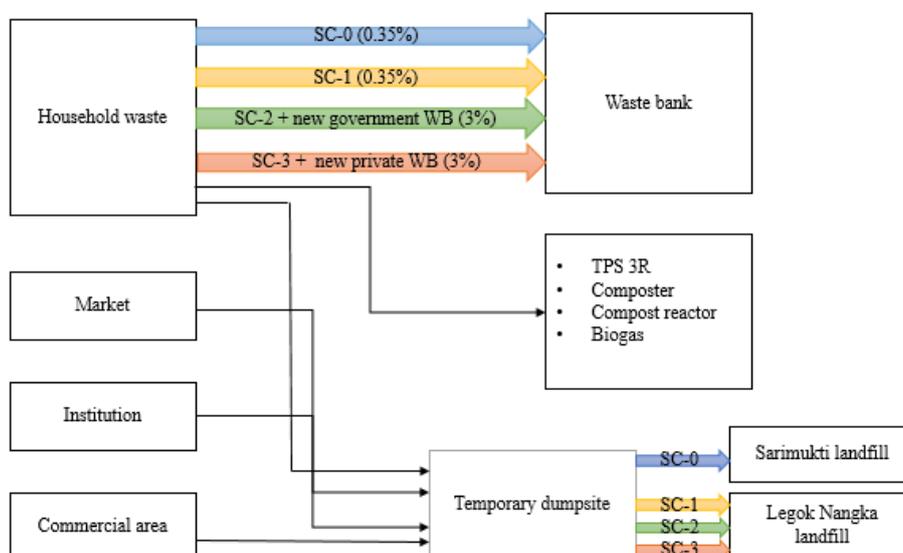


Figure 3. Scenarios of waste management in Cimahi city

3.2. Life cycle assessment

A. SC-0

According to the result of the existing condition (SC-0) estimation, final waste management resulted in the highest CO₂e emission. The CO₂e emitted to the environment due to the landfilling process of total waste in the landfill is written as an environmental indicator in the graphs. Hence environmental sector contributed 99.17% of CO₂e emitted. Organic waste itself contributed 49% to total CO₂e emitted or equal to 0.392 tonnes CO₂e per tonne waste managed. The collection phase produced 0.00041 tonnes of CO₂e per waste managed and transportation emitted 0.00602 tonnes CO₂e per tonne waste emitted. Emission emitted from Scenario SC-0 is shown in Figure 4.

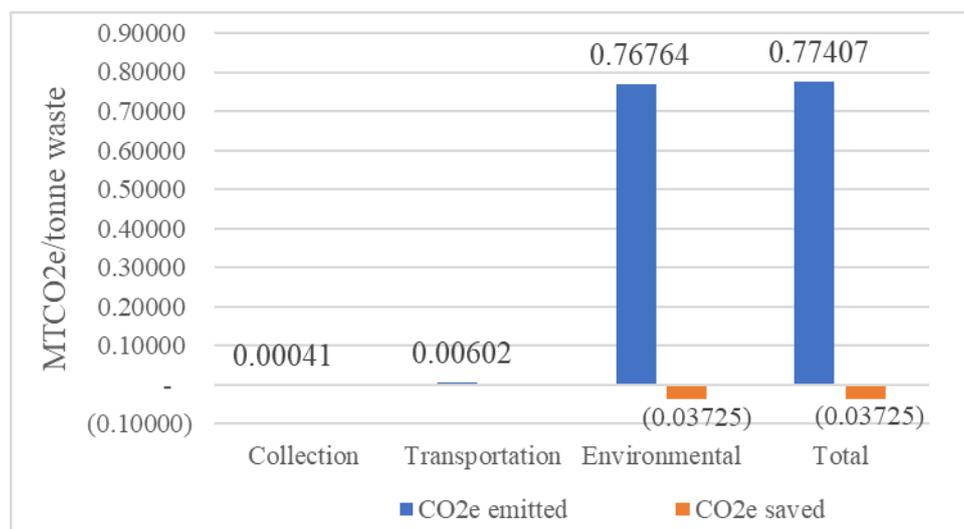


Figure 4. Emission emitted SC-0

There are saved CO₂e from the previously established waste bank and recycling activity which enable to avoid emission. Saved CO₂e estimated from the avoided raw material were substituted by recycled material in the manufacturing process and gives better impact to the environment rather than disposed to landfill. Recycling materials could reduce potential emissions caused by transportation and the acquisition of raw material. If those materials are not treated by the waste bank, then it will add to the number of wastes disposed to the landfill.

B. SC-1

Environmental impacts from scenario SC-1 are quite similar to SC-0. The only difference is DOI: <https://doi.org/10.7454/jessd.v4i1.1107>

the increase of CO_{2e} emitted from the transportation sector by 62.6%, since the change of landfill used affects the distance of travel. The change in distance of travel will also increase the fuel used by trucks. CO_{2e} saved is similar because the amount of waste disposal nothing changes. Annual CO_{2e} emitted of SC-1 compared with SC-0 is shown in Figure 5.

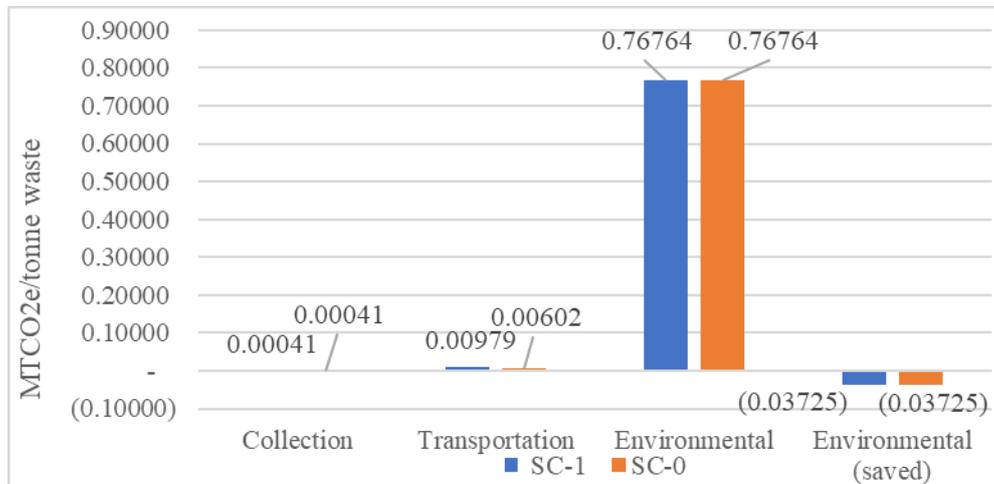


Figure 5. Annual CO_{2e} emitted of SC-1 compared with SC-0

C. SC-2

SC-2 resulted in lower CO_{2e} emitted from the transportation and collection sector compared with SC-1 since the amount of waste collected and transported to landfills is reduced. CO_{2e} emitted from the final waste management was reduced by 2.86% and emission from the collection phase was reduced by 25.1%. The decrease is caused by residents that brought their sorted inorganic waste directly to waste banks. This reduction is in line with the increase of saved CO_{2e} by 104.05% because the amount of raw material used in the recycling industry was also reduced. The reduction seems not significant since the amount of organic waste that contributes to the environmental impacts on landfilling is relatively high. A comparison of CO_{2e} saved and emitted between scenario SC-1 and SC-2 are shown in Figure 6.

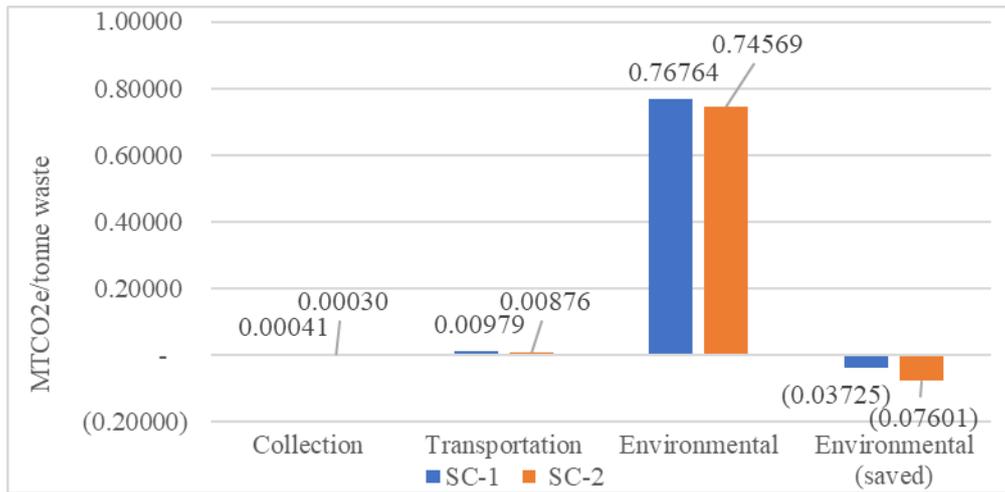


Figure 6. Annual CO₂e emitted of SC-1 compared with SC-2

D. SC-3

In SC-3 greenhouse gas emitted due to final treatment and collection decreased by 2.86% and 25.1% respectively, compared to scenario SC-1. Meanwhile, CO₂e saved increased by 104.05%. The reduction of CO₂e emitted and saved CO₂e in SC-3 is slightly different from SC-2 since the overall waste management system is similar, especially the amount of waste disposal to the landfill and treated in final treatment. Comparison of CO₂e emitted and saved between scenario SC- 1 and SC-3 is shown in Figure 7.

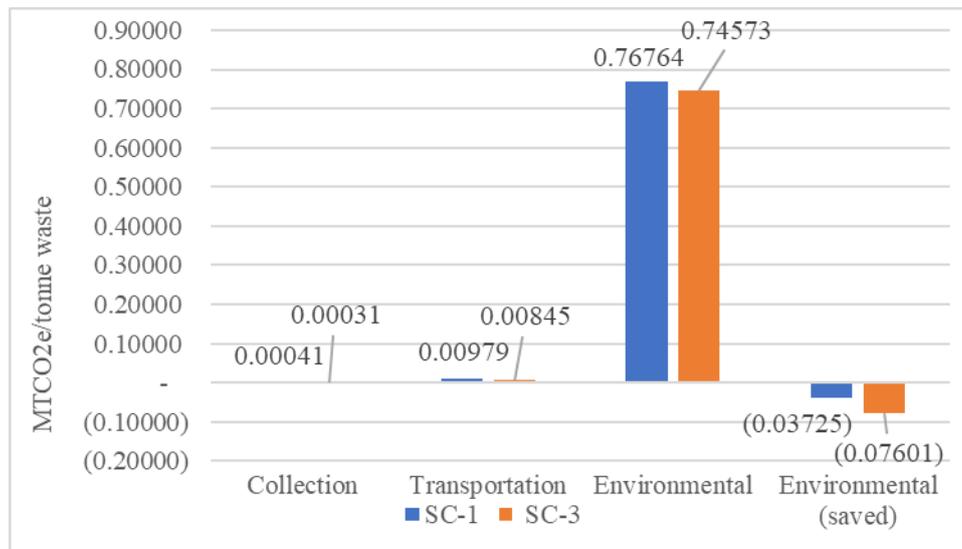


Figure 7. Annual CO₂e emitted of SC-1 compared with SC-3

3.3. Cost-benefit analysis

A. SC-0

Cimahi city is not considered as a large city with high a population like Jakarta city, Bandung city, or Medan city. This affects the costs and benefits resulted from waste management. One of the similarities with those big cities is the retribution fee. Retribution fee is considered as income for the municipality because every household, institution, and any type of commercial area has to pay the various amount of retribution fee depends on their scale. The average retribution fee per tonne waste managed equals IDR 12,941 per tonne annually. Another benefit acquired by SC-0 or existing waste management is from selling the recovered waste, which has been collected by waste banks.

Residents brought their sorted waste to the nearest waste bank, then the government-supported waste bank will collect it. Waste bank members did not receive their money directly, but they get informed about it by the end of the month. On average, the annual benefit per tonne of waste in Cimahi City is IDR 2,546,417 per tonne. Details of the cost-benefit SC-0 are presented in Table 3.

Table 3. Cost and benefit SC-0

Aspects		Cost	Benefit	Total Cost	Total Benefit
		(IDR / year.tonne)			
Internal	Retribution fee		12,491		
	Operation and Collection	36,857			
	Maintenance Transfer Point	308			
	MSW Transportation	35,703		503,642	2,526,320
	Landfilling	50,000			
	Waste Bank Selling Recyclable Items		2,513,829		
	Operational cost	380,774			
External	Collection (emission)	219			
	Transportation (emission)	3,248		417,637	20,098
	Environmental	414,170	20,098		
Total		921,279	2,546,417		

Operation and maintenance of municipal solid waste management consist of collection cost, transfer points maintenance, transportation cost, and landfilling cost. Collection costs

are affected by the number of households that need to be picked up, which also correlates with fuel, wage, and service fees. In the current scenario, collection costs IDR 36,857 per tonne, or about 7% of total internal costs annually. Transfer point maintenance fee does not contribute much to waste management costs since it does not need a lot of maintenance every year. Factors affecting transportation costs are the amount of waste disposal, since it will indirectly affect other factors, such as the number of trucks utilized, fuel consumed, wage, and service fee. In this scenario, it is assumed that all vehicles owned by the municipality for collecting and transporting waste are used.

Waste disposal to landfill annually reached 102,360 tonnes and costs IDR 35,703 per tonne. The landfill cost depends on the agreement between the regional government and the owner of the landfill, which is the provincial government. The operational cost of the waste bank was adapted from a previous study on the Pekanbaru waste bank and is equal to IDR 380,774 per year per tonne (Chaerul & Rahayu, 2019) because the data for the Cimahi waste bank are not available.

B. SC-1

In SC-1 the increase of transportation cost is 45% or IDR 15,994 per tonne. The landfilling cost increased by a higher margin equal to IDR 220,200 per tonne. External cost from transporting waste increased by 62%. It could be inferred that if there is no change in waste management, due to the change in landfill site the cost of solid waste management will increase by 25.9% or IDR 238,227 per tonne. The benefit to cost ratio (BCR) for SC-1 is 2.19. Details of the cost-benefit SC-1 are presented in Table 4.

Table 4. Cost and benefit SC-1

Aspects		Cost	Benefit	Total Cost	Total Benefit
(IDR / year.tonne)					
Internal	Retribution fee		12,491		
	Operation and Maintenance	Collection	36,857		
		Transfer Point	308		
	MSW	Transportation	51,697		
		Landfilling	270,200		
	Waste Bank	Selling Recyclable Items		2,513,829	729,835
					2,526,320

Aspects	Cost	Benefit	Total Cost	Total Benefit
(IDR / year.tonne)				
	Operational cost	380,774		
External	Collection (emission)	219		
	Transportation (emission)	5,282	419,670	20,098
Environmental		414,170	20,098	
Total		1,159,506	2,546,417	

C. SC-2

SC-2 compared to SC-1, collection cost is decreased by 10.4%, while transportation cost decreased by 8.7%. The decrease in cost is caused by the lower number of motor trucks utilized, which also affects the wage, fuel, and other fees related to the collection. Collection emission cost is decreased by 25.1%. The cost of transportation also decreased by 10.5% due to similar reasons with the decrease of collection cost. The avoidance of emission from the use of recovered material in the recycling industry increases the value of external benefit by IDR 20,910 per tonne of waste annually. BCR for scenario SC-2 is 2.25, slightly higher than SC-1. Details of the cost-benefit SC-2 are presented in Table 5.

Table 5. Cost and benefit SC-2

Aspects	Cost	Benefit	Total Cost	Total Benefit
(IDR / year.tonne)				
Internal	Retribution fee			12,491
	Operation and Maintenance MSW	Collection Transfer Point	33,008 319	
		Transportation	47,189	
		Landfilling	270,200	
	Waste Bank	Selling Recyclable Items		2,513,829
		Operational cost	380,774	731,491
External		Collection (emission)	164	
		Transportation	4,729	41,008
			407,215	

Aspects	Cost	Benefit	Total Cost	Total Benefit
	(IDR / year.tonne)			
	(emission)			
Environmental	402,322	41,008		
Total	1,138,706	2,567,328		

D. SC-3

SC-3 resulted in collection cost of IDR 33,213 per tonne, and transportation cost of IDR 45,977 per tonne. In this scenario, there is a new internal cost added, due to the addition of new private waste banks. Private waste banks buy the inorganic waste from the residents and sell it again for profit. Since the gateway of selling waste is only via a central waste bank, they have to transfer their waste there. Private waste banks buy the waste from residents and often pay them directly, then sell the waste slightly higher than buying price to get some profit. Those profits are also used to pay operational costs. The table below the private waste bank and the government-supported waste bank are separated, and this resulted in a total cost of IDR 3,838,451 per tonne and benefited IDR 5,081,159 per tonne. BCR for this scenario is 1.32. Details of the cost-benefit SC-3 are presented in Table 6.

Table 6. Cost and benefit SC-3

Aspects	Cost	Benefit	Total Cost	Total Benefit
	(IDR / year.tonne)			
Internal	Retribution fee	12,491		
	Operation and Maintenance MSW	Collection	33,213	
		Transfer Point	319	
		Transportation	45,977	
		Landfilling	270,200	
	Government supported waste bank	Selling recyclable items	2,513,829	3,431,377
		Operational cost	380,774	5,040,149
	Private waste bank	Selling recyclable items	2,513,829	
		Cost of buying waste	2,321,561	
		Operational cost	380,774	

Aspects	Cost	Benefit	Total Cost	Total Benefit
	(IDR / year.tonne)			
External	Collection (emission)	168		
	Transportation (emission)	4,561	407,074	41,011
	Environmental	402,345		41,011
Total		3,838,451		5,081,159

3.4. Comparison between scenarios

According to the environmental assessment, the comparison between SC-0 and SC-1 has increased slightly. The switch of landfill did not contribute significantly to the total CO_{2e} emitted, despite the distance is almost twice the previous distance. If we compare SC-1 with SC-2 and SC-3, there is a reduction equal to 0.06 tonnes CO_{2e} per waste managed. This happened due to the lower amount of waste disposal in the landfill. Increasing capacity of waste managed by the waste bank from 476 tonnes per year to 4122 tonnes per year affects to the reduction. The main emitter of CO_{2e} is organic waste, which reached 48,337 tonnes annually in SC-2 and SC-3 scenarios.

This finding is in line with previous research that the waste bank has the potential value to reduce CO₂ emissions from recyclable items (Khair, Rachman, & Matsumoto, 2019b). In order to decrease more CO_{2e} emissions, the Cimahi municipality local government has to do policy that supported composting or waste-to-energy. In order to do that, Cimahi city will be able to reduce the waste disposal to landfills and also reducing the CO_{2e} caused by the landfilling process. Graphic of CO_{2e} emitted comparison all scenarios show in Figure 8.

In all scenarios, the total benefit per tonne of waste managed weighs more than the total cost. The move to a new landfill, TPA Legok Nangka, caused an increase of total cost by IDR 238,227 per tonne, or equivalent to 26%. To prevent the increase in cost, it is proposed to establish more waste banks in Cimahi, either by government-supported or private waste banks. In SC-2, the waste bank is government supported waste bank, therefore there is not much difference with SC-1 except the cost becomes slightly lowered. In SC-3, the added waste banks are private. Thus, the waste bank needs to buy the waste from residents. A similar thing also happened in private waste banks in Batu City, East Java (Apriliyanti, Soemarno, & Meidiana, 2015).

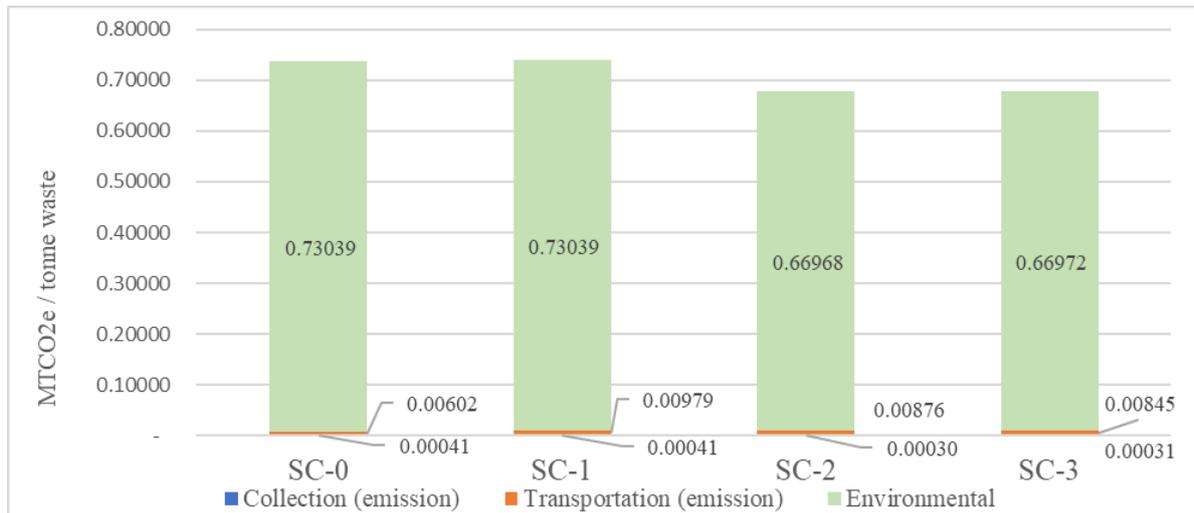


Figure 8. Comparison of CO₂e emitted all scenarios

Due to buying the waste then the cost is significantly increased, but so does the benefit. However, even the benefit has increased the benefit to cost ratio, which the bigger the number indicates whether the project is more profitable, is lower than SC-2. This has happened because the cost of operation is being borne to the private waste banks, and since they have to deliver the waste to the central waste bank, the collection cost is also borne to the private waste bank. Different from SC-2, in which those costs are borne by the government, therefore the operation of the waste bank could be more profitable. Comparison of cost and benefit for all scenarios are shown in Table 7 and Figure 9.

Table 7. Comparison of costs and benefits among all scenarios

Code	SC-0		SC-1		SC-2		SC-3	
	Cost	Benefit	Cost	Benefit	Cost	Benefit	Cost	Benefit
B1	-	12,491	-	12,491	-	12,491	-	12,491
C1	36,857	-	36,857	-	33,008	-	33,213	-
C2	308	-	308	-	319	-	319	-
C3	35,703	-	51,697	-	47,189	-	45,977	-
C4	50,000	-	270,200	-	270,200	-	270,200	-
B2	-	2,513,829	-	2,513,829	-	2,513,829	-	2,513,829
C5	380,774	-	380,774	-	380,774	-	380,774	-
B3	-	-	-	-	-	-	-	2,513,829
C6	-	-	-	-	-	-	2,321,561	-
C7	-	-	-	-	-	-	379,332	-
C8	219	-	219	-	164	-	164	-

Code	SC-0		SC-1		SC-2		SC-3	
	Cost	Benefit	Cost	Benefit	Cost	Benefit	Cost	Benefit
C9	3,248	-	5,282	-	4,729	-	4,729	-
C10 & B4	414,170	20,098	414,170	20,098	402,322	41,008	402,322	41,008
Total	921,279	2,546,417	1,159,506	2,513,829	1,138,706	2,567,328	3,838,451	5,081,159

(IDR/
year.to
nne)

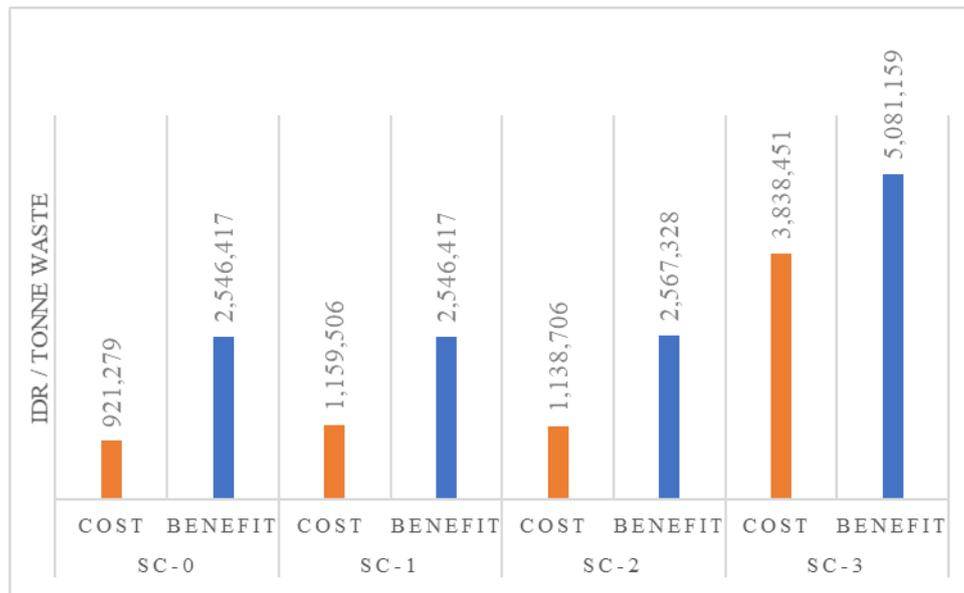


Figure 9. Cost and benefit comparison all scenario

Net present value (NPV) is used as a decision-making technique to select between alternative capital investments (Smith, 2002). NPV is the summation of the present value of cost and benefit of a project. As long as the NPV is not negative, then the project is acceptable. This means the higher NPV of an alternative, it is more preferable to implement the city waste management strategies. In this study, it is clear that among three alternative scenarios, SC-2 resulted in the highest NPV per tonne. NPV comparison all scenarios presented in Figure 10.

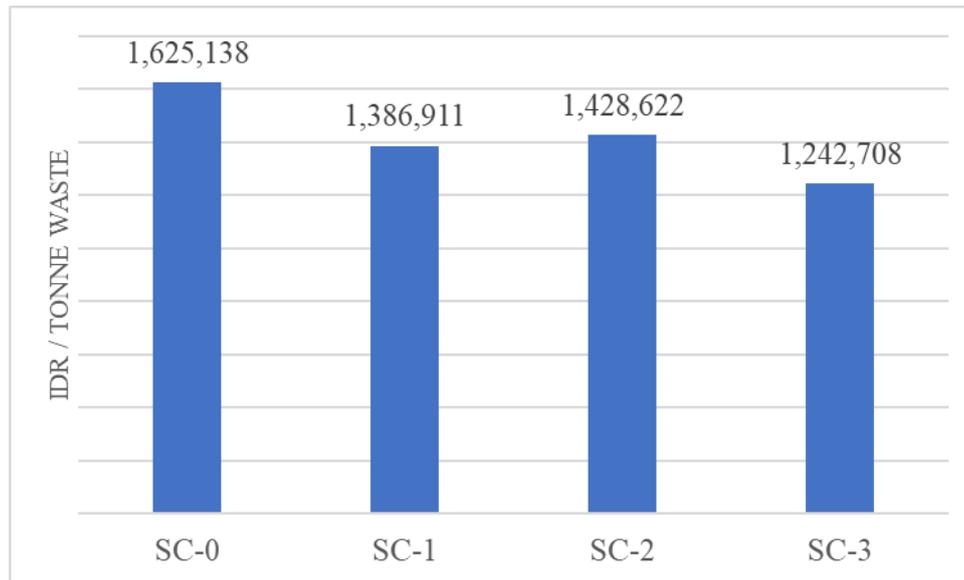


Figure 10. NPV comparison all scenario

3.5. Discussion

In 2016, Cimahi Municipality budgeted their waste management costs at IDR 188.625 per tonne of waste. Compared to the estimated cost per tonne, this amount is significantly lower than the required amount. The Cimahi government needs to reallocate its budgeted funds and pay more attention to waste treatment. By utilizing more waste banks, it would be possible to spend less and gain both environmental and economic benefits. The municipality should prioritize waste treatment rather than waste disposal, as this approach has a higher total benefit, and the measure is in line with the national policy on waste management (Chaerul & Rahayu, 2019).

According to this study, increment of waste treated by the government-supported waste bank to 3% (SC-2) will lower the overall cost per tonne of waste by IDR 20,800 compared to that with SC-1, and simultaneously increase the total benefit per tonne of waste managed by IDR 20,911. Compared to SC-1, SC-3 obtained the highest benefit per tonne by approximately 70% or IDR 2,678,945, while increasing the overall cost by 231% or IDR 2,678,945 per tonne of waste managed because of the need to buy waste from the community. According to the NPV comparison for all scenarios, SC-2 provided the highest NPV value equal to IDR 1,428,622. The addition of a waste bank provided an increased benefit, although the amount was not significant. This finding is in line with a previous study that although the number of people who benefit from such waste banks is not large, their

impact is felt directly and the surroundings become clean and green (Wulandari, Utomo, & Narmaditya, 2017).

Efforts in waste management that require participation from residents should receive support from and be coordinated with the local government to ensure that they persist (Puspasari & Mussadun, 2017). Subsidiary waste banks can be established in the neighborhood or be institution- or community-based (Yustiani, 2019). Utilizing institutions to establish a waste bank has a downside, which is that the flow of waste is not constant, and the amount will be less than that from a community-based waste bank. Promoting at-source waste sorting is important; however, appropriate end-of-pipe technologies for the treatment of MSW are also required (Aprilia, Tezuka, & Spaargare, 2012). According to studies on waste utilization, recycling through waste bank activities can reduce waste disposal to landfills and extend the lifetime of landfills (Isharyati, Prasetya, & Cahyono, 2019). This will affect the investment reduction cost for landfills. In Indonesia, scavengers also play a major role in solid waste management in cities and can be promoted to store solid waste for recycling by assisting the government in the appropriate management of solid waste (Prasetyanti, 2014).

Furthermore, waste banks can become more efficient and capable of managing large quantities of wastes by incorporating innovative tools because of the vast potential for recyclable wastes (Khair, Siregar, Rachman, & Matsumoto, 2019). According to the findings of this study, the addition of a waste bank could be an alternative to reduce the cost of waste disposal and reduce greenhouse gas emissions. It is easier to establish a waste bank through local government policy rather than depend on the initiatives of the residents. The Cimahi City government and every region in Indonesia should consider building community-based waste management resources because of their wide benefits.

4. Conclusion

In this study, we found that the switch from TPA Sarimukti to TPA Legok Nangka as the landfill site contributed to an increase in the total CO₂e emitted, although this difference was not significant despite the distance being nearly twice that of the previous site. The primary contributor to CO₂e emissions from the final treatment is organic waste. The addition of waste banks only contributes to reducing emissions from fuel consumed by the collection and transportation steps. SC-2 and SC-3 resulted in a similar reduction in terms of CO₂e emission

in the environment compared to that with SC-1. Increasing the number of waste banks could be an alternative to reduce the cost of disposing waste to landfills. Increment of waste treated by the government-supported waste bank to 3% (SC-2) will lower the overall cost per tonne of waste and simultaneously increase the total benefit per tonne of waste managed. Compared to SC-1, SC-3 which is addition of private waste bank obtained the highest benefit per tonne by approximately 70%, while increasing the overall cost by 231% per tonne of waste managed because of the need to buy waste from the community. According to the NPV comparison for all scenarios, SC-2 with the government waste bank addition provided the highest NPV value equal to IDR 1,428,622.

Considering the environmental and economic aspects, SC-2 is preferable for implementation in Cimahi City. The government needs to be more concerned about waste treatment. By utilizing more waste banks, it would be possible to spend less and gain both environmental and economic benefits. Increasing the number of waste banks should be followed by educating the residents on the importance of recycling waste. This study has a limitation in that it only considers waste banks as an alternative recycling activity. Future research should investigate the potential environmental and economic aspects of other waste treatment options.

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Author Contribution

Qiyam Maulana Binu Soesanto, Laksamana Rayhan Utomo, and Indriyani Rachman gave an idea and conceptualization regarding municipal waste management strategies in Cimahi City, then discuss with Prof. Toru Matsumoto. The methodology used life cycle assessment and cost-benefit analysis improved by Qiyam, Laksamana, Indriyani and Prof. Matsumoto. Data input and calculation in work sheet were done by Qiyam and Laksamana. Formal analysis output of life cycle assessment and cost-benefit analysis were done by Qiyam, Laksamana, and Indriyani. Original draft and preparation were done by Qiyam and Laksamana. Editing and visualization by Qiyam. All the manuscript preparation process and review under the supervision of Prof. Matsumoto.

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