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Evaluating Economic and Environmental Impact of A Plastic Waste Processing Industry Based on Circular Economy Using Benefit-Cost Analysis

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Abstract. *Plastic has played a dominant role in human life as its usage is increasing over time. Plastic waste can harm the environment because plastic is not biodegradable. A collaboration adopted from the quintuple helix model was initiated by the local government of Cilegon, Indonesia, industry, and community to tackle the plastic waste problem. Plastic waste from households and industry is collected and processed in the plastic waste processing industry using the pyrolysis method producing gasoline, diesel, and kerosene. Kerosene is used by the community as fuel for cooking, whereas diesel and gasoline are used as boat fuels by fishermen. The collaboration is expected to provide economic and environmental benefits for the people in the Cilegon area. We conducted a cost and benefit analysis to evaluate the feasibility of this project from an economic and ecological point of view. The results will be used as input for conducting similar projects in other cities.*

Keywords: *quintuple helix model; plastic waste; economic and ecological impact; benefit-cost analysis*

I. INTRODUCTION

Plastic is an essential material used for packaging, consumer products, transportation, building and construction, and many other things. As of 2015, the global amount of plastic produced was around 6300 million metric tons, about 21% being managed (9% recycled and 12% incinerated) and the remaining 79% being unmanaged accumulated in landfills or the environment (Geyer, Jambeck, and Law 2017). It is estimated that the amount of plastic in the oceans was around 4-12 million metric tons in 2010 and is increasing every year (Jambeck et al. 2015). Due to the non-biodegradable nature of plastic, plastic waste on land and ocean surfaces certainly brings bad consequences for humans and ocean ecosystems. If not managed properly, it will potentially contribute to environmental damage (Murphy et al. 2021).

The usage of plastic products is very rapid in Indonesia, ranging from packaging and household needs. This increase in the use of plastic causes problems in the form of environmental pollution because plastic is a difficult material to degrade. The waste problem in Indonesia is complex because of the community's increasing standard of living, which is not accompanied by public knowledge of the consequences that can be caused by waste. The management of this plastic waste must start from the household. People's attitudes, knowledge, and behaviour are important components in managing waste, including plastic waste management. The public needs to understand and educate the dangers of plastic waste and the potential for waste management to be reused.

Like any city in the world, Cilegon city has also faced the waste problem. The city of Cilegon, part of Banten province in Indonesia, has an area of 175.5 km² with eight sub-districts, 43 urban villages, and 295,738 people with a total waste

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generation of 1,345.05 m^2 per year (Ismiandini, Yuniar, and Hikmawan 2020). Industrial and technological advances and population growth cause the increased use of plastics. Plastic waste management is a step that must be taken to reduce environmental pollution, and the waste produced will be of economic value. Industry, academia, government, and the community must collaborate to find solutions for environmental protection.

A multinational company in Cilegon, namely company X, has initiated a pilot project of plastic waste management based on the circular economy concept in collaboration with the local government, university, and a local community group. Plastic waste from households and industries is collected and processed in the integrated plastic waste processing industry (PPI) using pyrolysis technology, producing gasoline, diesel, and kerosene. Kerosene is used by the community as fuel for cooking, whereas diesel and gasoline are used as boat fuels by fishermen. The company believes that the IPP can be established in other areas if the current project can significantly impact the environment and economy. The government provides support for facilities and policies in waste management. University academics research that waste processing using pyrolysis technology can produce high-quality fuel at low costs.

The currently popular technology used to treat plastic waste is by placing it in landfills (Ospanbayeva and Wang 2020), recycling (Genc, Zeydan, and Sarac 2019; Medina-Mijangos et al. 2021), and incineration (Gradus et al. 2017). Recently, researchers have begun to examine the potential of the pyrolysis process as an alternative to waste management (Czajczyńska et al. 2017). In the pyrolysis process, plastic waste is heated to produce oil that can substitute for fuel oil (Csukás et al. 2013; Mangesh et al. 2020; Pacheco-López et al. 2021; Wu et al. 2017).

Therefore, research on the types of plastics on the quality of the oil produced from pyrolysis has also attracted the interest of researchers (Jamradloedluk and Lertsatitthanakorn 2014; Miandad et al. 2017; Quesada et al. 2019; Singh and Ruj 2016).

Currently, the pyrolysis process still results in high costs compared to the market price of fuel oil (Fivga and Dimitriou 2018). Therefore, it is urgent to evaluate the impact of the PPI project on the environment and the local community's economy. To that end, this study measures the benefit of this project using benefit-cost analysis (BCA). BCA is a method used to assess the feasibility of a project where intangible benefits arise, especially projects that are expected to have a good environmental impact (Babalola 2020; Cropper et al. 2019; Dobraja, Barisa, and Rosa 2016; Gong, Kung, and Zhang 2021; Ning et al. 2013; Torkashvand et al. 2021; Yahya et al. 2021). We also perform sensitivity analysis on parameters under several scenarios. The results can be used as input for improvements if other similar projects are applied in other places in the future.

II. Research Method

Integrated Plastic Waste Processing Industry (PPI) based on Circular Economy

The integrated waste processing industry receives waste from various sources, namely households, schools, commercial, fishers, and industries. After that, the waste is sorted into plastic and non-plastic waste. The plastics waste are categorized as high-value plastics waste and low-value plastic waste. High-value plastic waste such as bottles and drinking glasses, hardened plastics, other packaging bottles, and electronic plastics will be sorted and sold to the recycling industry. Low-value plastic waste such as crackle bags, clear bags, sachets, aluminum packaging, and other packaging will be processed through a pyrolysis machine.

IPP conducts inspections or inspections in advance of raw materials from suppliers. However, in managing raw materials, IPP first chops the plastic waste into a fine powder to process the raw materials in the pyrolysis machine. Therefore, the raw materials that have been chopped from the chopping machine will be stored in the warehouse and then processed on the pyrolysis machine.

The IPP production process is carried out every Monday to Saturday; working hours are eight hours/day or 40 hours/week. The number of employees at IPP consists of two women and eight men. Every production is done by the same employee, excluding women. In one day, it can produce plastic bagasse with a capacity of 100 kg/day, and the resulting product can reach 70-80 litres of pyrolysis fuel.

The production process begins by entering the crushed crackle waste into a pyrolysis machine, then heating the crackle waste using a large stove/furnace with a maximum temperature of about 450 degrees. Then the crackle waste will melt into liquid oil, and then the liquid will be condensed first and then accommodated by a bucket. After that, the pyrolysis fuel is finished and put into the drum for storage. Several kinds of pyrolysis fuel are gasoline, kerosene, and diesel. In the pyrolysis process, the first type of oil is gasoline, then kerosene, followed by diesel. All types of pyrolysis fuel obtained by IPP have been approved as a viable fuel by Cilegon authority.

The customers of the IPP are the surrounding community. Customers can order pyrolysis fuel by placing an order directly to the production site. In addition, customers can also place orders through the employees who produce the fuel. At this time, there is no transportation medium for sending fuel oil orders from IPP. So, customers can take the order by going directly to the place of production.

The IPP always makes announcements to the public about how to buy the results from processing plastic waste, and then if there are people who want the fuel oil, they can exchange this pyrolysis fuel product for plastic waste. Then if the community is diligent in depositing plastic waste to the site, the IPP will give the community a gift in the form of shopping vouchers. The framework of the IPP based on circular economy is depicted in Figure 1.

Benefit

We collected data from observations and interviews with the company representative, PPI manager, and the local community to determine the benefits and costs of establishing PPI. Other data collected in this study are nominal data obtained from the study results of documentation on financial statements and other documents, literature relevant to the study from several sources.

The impact of PPI can be distinguished by benefits obtained from the establishment of PPI and the costs incurred for organizing the

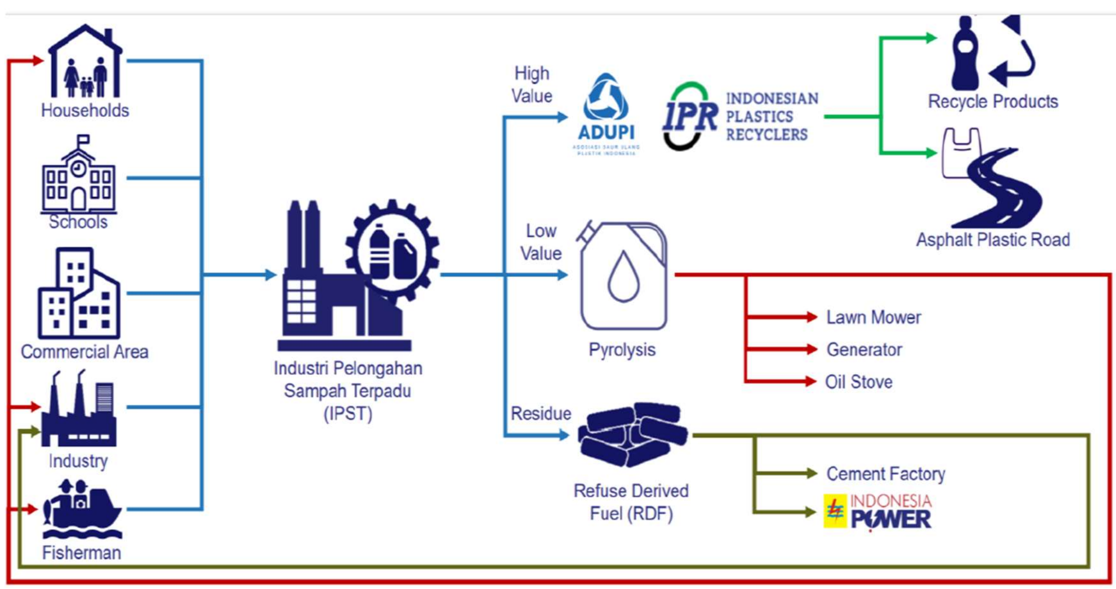

Figure 1. Integrated Waste Management Based on Circular Economy

establishment of PPI. With the establishment of the PPI, it can generally provide direct benefits, namely the benefits arising from the PPI, and indirect benefits, namely the benefits that arise from the PPI but appear outside the PPI. The direct benefits and indirect benefits are as follows.

Direct benefits are obtained from the PPI project and can be felt directly by residents and the surrounding environment. The direct benefits of having PPI are as follows:

a. Local community get cheap fuel. The product produced from the pyrolysis process of waste processing based on circular economy produces fuel oil in the form of kerosene, gasoline and diesel. In one pyrolysis process, plastic waste will be processed with a capacity of 100 kg. The pyrolysis process will produce 75 litres of fuel oil for one batch. In one week, the pyrolysis process will be carried out twice, which will produce 150 litres of fuel oil. With a selling price of Rp. 11,000 per litre of fuel oil (kerosene, seeds, diesel).
b. Local community gets income from selling high-value plastic. The IPP collects high-value plastics such as bottles, drinking glasses, and other plastics or atoms. The high-value plastic will be collected and sold to the recycling industry. The high-value plastic in one year can be collected approximately 0.408 tons and will be sold to the recycling industry.
c. Benefit for recycle actor. With the IPP, the recycling industry players have the convenience of getting the supply of plastic waste obtained from the IPP. The average profit obtained by the recycling industry is 44%. So the recycling industry players can get a net profit of approximately Rp.880,000/year with 0.3 tons of plastic waste.
d. Benefit for the employee. IPP utilizes a group of non-governmental organizations in the IPP area as a workforce, ten workers with an average income of one person per month, which is Rp. 2,000,000.
e. Benefit for the community without pay retribution. Before the project existed, the waste was transported by the landfill, and each household was charged Rp. 20,000 per month. At the time of the establishment of IPP, all the costs of transporting waste by IPP were not charged for every community that lived near IPP, approximately 109 households.
f. Cost reduction at landfill. With the IPP, it is estimated to reduce the number of workers in the landfills by five people in the transportation section. There will also be a reduction in the costs incurred by the landfills for the cost of workers' salaries. With the existence of IPP also reducing transportation trucks by 1 unit, there will also be a reduction in fuel oil consumption which is estimated to be in 1 year as much as 768 litres of gasoline.
g. Reducing the need for land in landfills. With the IPP, the waste sent to the landfill will be reduced, and the need for land required for the landfill will be reduced by 863.28 m^3/year.

Salvage value of pyrolysis machine and transportation equipment. The salvage value is the estimated value of property, plant, and equipment at the end of their useful life. The salvage value depends on the property's economic life, plant, and equipment after use. In IPP, there is a residual value calculation for the pyrolysis machine and transportation equipment with an economic period of 10 years.

Indirect benefits are benefits that arise in a project but impact the project's existence. Indirect benefits can increase the community's income around the project site (cannot or is difficult to measure). The indirect benefits from PPI are:

a. Reduction of carbon dioxide emissions from transporting waste to landfill. It is estimated that there will be a reduction in 1 truck transport and a reduction in CO2 emissions caused by the waste transportation process.
b. Reduction of methane gas in landfill. It is estimated that there will be a reduction in CH4 gas emissions at the landfills because some of the waste has been reduced at the IPP.
c. Reduction of the impact of health costs. There will be a reduction in costs due to health impacts, estimated using case studies of diseases related to waste. The hospital and caring cost is calculated based on the tariffs from the decree of Ministry of Health.

The direct and indirect benefits are summarized in Table 1.

Table 1. Benefit of IPP Project

No.	Benefit	Amount (IDR)
1	Cheap fuel for local community	79,900,000
2	Revenue from high-value plastic	2,000,000
3	Benefit for recycler actor	2,800,000
4	Employment for local community	240,000,000
5	Waive retribution fee	26,160,000
6	Cost reduction at landfill	19,412,000
7	Reducing the need for land in landfills	25,898,000
8	Salvage value for pyrolysis machine	75,000,000
9	Salvage value for transportation vehicle	10,000,000
10	Reduction of carbon dioxide emissions from transporting waste to landfill	10,875
11	Reduction of methane gas in landfill	11,678,750
12	Reduction of the impact of health costs	138,699,488

Table 2. Cost of IPP Project

No.	Cost	Amount (IDR)
1	Building	800,000,000
2	Machine	315,000,000
3	Transportation vehicles	50,000,000
4	Manpower	240,000,000
5	Electricity	2,016,000
6	Fuel	1,600,000
7	Lubricant	400,000
8	Transportation fuel	12,960,000
9	Maintenance	1,000,000
10	Machine depreciation	24,000,000
11	Vehicle depreciation	4,000,000
12	Emission from transportation	66,000
13	Emission from processing	655,000

Cost

We categorized the cost associated with the project are as direct and indirect costs. The direct costs incurred in the PPI project are: investment costs (land, building, pyrolysis machine, and vehicles), operational costs (labour, utility, raw material, transportation, and retribution), maintenance costs, and depreciation costs (machine and vehicle).

Indirect costs are costs incurred for activities that are not directly related to the PPI project. The indirect costs of PPI are caused by pollution by activity, including costs incurred due to emissions from waste transportation and processing activities. In detail, the indirect costs consists of emission from transportation cost and waste processing. IPP transports waste from residents' homes to IPP using 2 small vehicles, so that there will be environmental pollution in the form of costs incurred due to emissions from transportation activities in the form of CO_2.

IPP performs waste processing using a pyrolysis machine, so there will be environmental pollution in the form of costs incurred due to emissions from processing activities in the form of CH_4.

III. Result and Discussion

We perform the analysis of cost components and benefit components at the PPI project using the Benefit-Cost Analysis (BCA) method, then test the sensitivity of the PPI project and propose improvement scenarios from the PPI project. Cost-benefit analysis to analyze and compare a series of benefits and costs of the PPI project aims to compare the two values accurately, which

Table 3. Projected benefit and cost of IPP project (MARR = 3.5%)

Year	Cost (million IDR)	Benefit (million IDR)	PV Cost (million IDR)	PV Benefit (million IDR)
0	1165	0	1165	0
1	296	461	286	416
2	295	461	275	431
3	295	485	266	438
4	295	545	257	475
5	295	545	248	459
6	295	545	240	444
7	295	545	232	429
8	295	545	224	414
9	295	545	216	400
10	295	545	209	447

Table 4. Projected benefit and cost of IPP project (MARR = 6.5%)

Year	Cost (million IDR)	Benefit (million IDR)	PV Cost (million IDR)	PV Benefit (million IDR)
0	1165	0	1165	0
1	296	461	278	433
2	295	461	260	407
3	295	485	244	402
4	295	545	229	424
5	295	545	215	398
6	295	545	202	374
7	295	545	189	351
8	295	545	178	329
9	295	545	167	309
10	295	630	157	336

is more significant. In this benefit and cost analysis, benefit components consist of direct and indirect benefits and cost components consisting of direct and indirect costs. This analysis (BCA) is the first step to identify each component, namely the benefit component and the cost component of implementing the PPI project. All components must be appropriately identified.

The assumptions used in conducting BCA are as follows. Plastic waste processed is 800 kg per month. The minimum attractive rate of rate (MARR) is set at 3.5%. The economic life is ten years—depreciation using the straight-line method. Table 3 shows the calculation results of BCA currently in the IPP. The ratio for this setting is 1.211.

From Table 3, it can be concluded that the IPP project is feasible because the BCR ratio produces a value of more than 1. Table 4 shows projected benefit and cost if MARR is increased to 6.5%. In this setting, BCR is 1.146 and is still feasible and attractive. However, the BCR is slightly decreased compared with when MARR is 3.5%.

However, it should be noted that this project requires a considerable investment, which is about 32% of the total cost over the life of the project (discounted investment cost divided by discounted total cost). In addition, it is assumed that the supply of plastic waste products is available in sufficient quantities and is always available. To anticipate the supply of waste, company X collaborates with local governments, universities, and the community to collect waste through the digital bank password application. The first stage is the creation of the application. In the next stage, the public learned the importance of managing plastic waste using the bank code application.

IV. Conclusion

This study aims to demonstrate the BCA method for analyzing the impact of an integrated plastic waste processing project using the pyrolysis method. This project is a pilot project initiated by a plastic manufacturing company in the Cilegon area, Indonesia. The results from BCA can be used to provide an overview of areas that can be improved if the company and local government plan to add similar projects in other areas. Based on the analysis, this project requires an expensive investment and also a large supply of waste. Therefore, this project requires a strong commitment from the government, industry, academia, and the community so that this project can be sustainable.

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