Reduction of Greenhouse Gas Emissions through Community-Scale Pyrolysis Technology in Bogor City and its Financial Feasibility

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ABSTRACT

Population growth affects the generation of plastic waste and could potentially increase greenhouse gas (GHG) emissions through the burning process. This has become a severe problem as it contributes to global warming. Therefore, plastic waste management is required, for instance, by using pyrolysis technology on a community scale. Such a project will reduce plastic waste and GHG emissions by processing plastic into valuable products. This study aims (1) to estimate potential GHG emissions before the project implementation, (2) to estimate potential GHG emissions reduction after the project implementation, and (3) to assess both potential revenue and profit of pyrolysis products. This study employs SNI 19-3694-1994 method to estimate household waste generated, the clean development mechanism (CDM) method to estimate GHGs emissions reduction, and the profit comparison method (PCM) to asses both revenue and profit of pyrolysis products. The results show that GHG emissions before the project will be 3.69 t CO2e in 2021 and could increase to 4.61 t CO_2e in 2030. Potential GHG emissions reduction depends on the fuel types to heat the reactor. Only electric pyrolysis will reduce GHG emissions by up to 0.46 t CO_2e (13%) annually. This project is not financially feasible because operational costs (15,772,779 IDR) exceed the annual revenue (1,014,000 IDR).

Keywords: CDM, climate change, GHG emission, plastic waste, pyrolysis

INTRODUCTION

Climate change is a global problem caused by an increase in greenhouse gas (GHG) emissions such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons. CO2 gas is one of the most significant contributors to GHGs in the atmosphere (Lasmono & Avia, 2014). As a result, since the end of the 19th century, the Earth's temperature has increased by about 1°C (1.6°F) (The Royal Society, 2021).

In 1992, the United Nations (UN) formed an international agreement, namely the United Nations Framework Convention on Climate Change (UNFCCC), to overcome the increase in the Earth's temperature. They produced the Kyoto Protocol on the agenda of the 3rd Conference of the Parties (COP) in Kyoto, Japan (IESR, 2005). The Kyoto Protocol is an international agreement to reduce global warming that is legally binding with three mechanisms, namely emission trading (ET), joint implementation (JI), and clean development mechanism (CDM) (Sugiyono, 2001). The CDM is the only mechanism that involves developing countries in reducing GHG emissions.

Indonesia responded to the agreement by ratifying the climate change agenda and setting a GHG emission reduction target for 2030 of 29% by its efforts and 41% with international assistance (Sugiyono, 2006; KLHK, 2017). In addition, Indonesia established a work plan to implement activities that can reduce the impact of climate change, namely the national action plan for reducing greenhouse gas emissions (RAN GRK). According to RAN GRK, the primary sectors for mitigation action are forestry and land, energy, waste, agriculture, and industry (LAN, 2018).

The waste sector is a potential sector for reducing GHG emissions through environmentally friendly waste management due to increasing waste, population growth, and changes in consumption patterns, especially plastic waste. Burning plastic waste is a fast waste management effort that is widely applied and can potentially contribute to CO2 emissions and risks to human health if not appropriately managed; this threatens the environment and humans (Sahwan et al., 2005).

To tackle plastic waste management, Bogor City banned the use of plastic in shopping centers since 2018. (Diskominfo, 2021). However, the implementation of this ban has not been widespread yet. Efficient management of plastic waste at the community level is necessary, and one effective method is the use of pyrolysis technology starting from the source, i.e. households. Pyrolysis technology converts plastic waste into liquid fuel through a decomposition process by heating without oxygen or thermal cracking (Surono, 2013). Pyrolysis-based plastic waste management could provide economic benefits and help Bogor City reduce plastic waste..

More research is needed to determine the feasibility of using pyrolysis technology, particularly with regard to the potential reduction of emissions and the revenue that can be generated from the resulting products. Public acceptance of these products also needs to be taken into account..

The aim of this study is to evaluate the amount of greenhouse gas (GHG) emissions that could occur before the community-scale pyrolysis project, and the potential reduction of GHG emissions after the implementation of the said project. Additionally, this study will analyze the potential revenue and profit that could be generated from the products of the pyrolysis process.

MATERIALS AND METHODS

Location and Time of Research

The research was conducted in the Villa Tajur Community, Sindangrasa Village, Bogor City, using waste sample data from 14 houses. This research started from July 2020 to March 2021.

Data Analysis Method

1. Total Waste Generated

The method of calculating total waste generated followed the procedure of SNI 19-3964-1994. The total generated of x types of waste in the community was grouped into four types with an index of x = 1,2,3,4 (1 = organic waste, 2 = pads and diapers, 3 = residual plastic, 4 = recycled waste). The calculation for total waste generated in the community (W_y), is according to Equation 1.

$$W_y = H \times 365 \times \sum_{x=1}^{4} \bar{w}_{x,i} \quad (1)$$

Description:

W_y = total waste generated in Villa Tajur Community in year y (kg/year)
H = number of households contributing waste (houses)
x = type of waste produced
i = number of respondents who contribute waste (house)
$\bar{w}_{x,i}$ = average daily waste type x generated by respondent i (kg)

Sampling of total waste generated in the community was conducted for n days or eight consecutive days. Then, the average daily waste type x by respondent i i ($\bar{w}_{x,i}$), is calculated according to Equation 2.

$$\bar{w}_{x,i} = \frac{1}{n} \sum_{n=1}^{8} w_{x,i,n} \quad (2)$$

Description:

n = number of days of observation (days)
$w_{x,i,n}$ = daily waste of type x in n days of observation generated by respondents (kg)

2. GHG emission reduction

The analysis method used in calculating GHG emission reductions is the AMS-III.L method, one of the CDMs for small scale from the UNFCCC. Emission reduction (RE) is estimated (Equation 3).

$$RE_y = BE_y - PE_y \quad (3)$$

Description:

RE_y = GHG emission reduction in year y (t CO_2e/year)
BE_y = baseline GHG emissions in year y (t CO_2e/year)
PE_y = project GHG emissions in the year y (t CO_2e/year)

This study's project boundaries of emission reduction refer to the pyrolysis reactor capacity of 2 kg/round, assuming one day can process three rounds. The operation of the pyrolysis project, where residual plastic waste is obtained from 50 houses, is only carried out five working days a week.

Baseline Emissions

The sources of baseline emissions are CO2 and CH4 gases from the decomposition of organic waste in landfills and transportation emissions from waste carriers. Baseline emissions (BE) were calculated using the CDM method from the UNFCCC (Equation 4).

$$BE_y = BE_{MWSL,y} + BE_{TR,y} \quad (4)$$

Description:

BE_y	=	baseline GHG emissions in year y (t CO_2e/year)
$BE_{MSWL,y}$	=	baseline methane emissions occurring in year y resulting from waste disposal at Galuga landfill during the time ending in year y (t CO_2e/year)
$BE_{TR,y}$	=	baseline emissions from waste transportation in the monitoring year y (t CO_2e/year)

$BE_{MSWL,y}$ estimation using Tool 04 "Tool Emissions from Solid Waste Disposal Sites" (tool for calculating emissions from waste disposal sites) version 08 (UNFCCC, 2020) according to Equation 5.

$$BE_{MWSL,y} = \varphi_y \times (1 - f_y) \times GWP_{CH4} \times \sum_{y=1}^{y} Default_y \times W_y \quad (5)$$

Description:

$BE_{MWSL,y}$	=	baseline methane emissions occurring in year y resulting from waste disposal at Galuga landfill during the time period ending in year y (t CO_2e/year)
φ_y	=	model correction factor to account for model uncertainty in year y
f_y	=	fraction of methane gas captured at Galuga landfill and flared or used in another way that prevents methane emissions to the atmosphere in year y
GWP_{CH_4}	=	global warming potential of methane gas (t CO_2e/t CH_4)
$Default_y$	=	standardized value in year y that depends on waste properties and climate zone
W_y	=	the amount of solid waste disposed of in Galuga landfill in year y (kg/year)

Estimation of $BE_{TR,y}$ using Tools 12 "Tool Project and Leakage Emissions from Transportation of Freight" version 01 (UNFCCC, 2020b) (Equation 6).

$$BE_{TR,y} = \sum_{f=1}^{F} D_{f,y} \times FR_{f,y} \times EF_{CO2,y} \times 10^{-6} \quad (6)$$

Description:

$BE_{TR,y}$	=	baseline emissions from waste transportation in the monitoring year y (t CO_2/year)
$D_{f,y}$	=	round-trip distance between Villa Tajur Community site and Galuga landfill using garbage truck f in monitoring year y (km
$FR_{f,y}$	=	total weight of waste transported to Galuga landfill in garbage truck f in monitoring year y (tons)
$EF_{CO2,y}$	=	standard CO_2 emission factor for waste transportation by garbage trucks f (g CO_2/t km)

Project Emissions

The project emission sources consist of CO2 emissions from the pyrolysis combustion, auxiliary fuel consumption, transportation, and electricity consumption. Project emissions are estimated based on the scenarios created and calculated by the

AMS-III.L and Tools 12 method (Equation 7).

$$PE_y = PE_{y,pyro} + PE_{y,fuel} + PE_{y,transp} + PE_{y,power} \quad (7)$$

Description:

PE_y = emissions from project activities in year y (t CO_2e/year)

$PE_{y,pyro}$ = emissions from fuel usage for the pyrolysis process in year y (t CO_2e/)

$PE_{y,fuel}$ = emissions from fossil fuel use due to additional transportation in year y (t CO_2e/year)

$PE_{y,transp}$ = standard CO_2 emission factor for waste transportation by garbage trucks f (g CO_2/t km)

$PE_{y,power}$ = emissions from electricity or diesel usage in year y (t CO_2e/year)

$PE_{y,pyro}$ estimated using AMS-III.L method (UNFCCC, 2020a) (Equation 8).

$$PE_{y,pyro} = Q_{y,non-biogenic} \times E_{non-biogenic} \quad (8)$$

Description:

$PE_{y,pyro}$ = emissions from pyrolysis containing non-biogenic carbon in year y (t CO_2e/year)

$Q_{y,non-biogenic}$ = quantity from pyrolysis of non-biogenic waste in year y (ton)

$E_{non-biogenic}$ = carbon dioxide gas emission factor for pyrolysis of the non-biogenic fraction of waste treated by the project (t CO_2e/ton of non-biogenic waste)

$PE_{y,fuel}$ estimated using small-scale CDM AMS-III.L (UNFCCC, 2020a) (Equation 9).

$$PE_{y,fuel} = Q_{y,fuel} \times E_{fuel} \quad (9)$$

Description:

$PE_{y,fuel}$ = emissions from fuel usage for the pyrolysis process in year y (t CO_2e/year)

$Q_{y,fuel}$ = total fuel usage in year y (ton)

E_{fuel} = carbon dioxide gas emission factor for pyrolysis of auxiliary fuels (t CO_2e/tons of fuel)

$PE_{y,transp}$ estimated using *Tools* 12 (UNFCCC, 2020c) (Equation 10).

$$PE_{y,transp} = \sum_{f=1}^{F} D_{f,y} \times FR_{f,y} \times EF_{CO2,f} \times 10^{-6} \quad (10)$$

Description:

$PE_{y,transp}$ = project emissions from waste transportation in the monitoring year y (t CO_2/year)

$D_{f,y}$ = the round-trip distance between the Villa Tajur Community site and the project site using the motorized waste cart f in the monitoring year y y (km)

$FR_{f,y}$ = total weight of waste transported to the project site in motorized waste cart f in the monitoring year y (t)

$EF_{CO2,f}$ = standard carbon dioxide gas emission factor for waste transportation by garbage trucks f (g CO_2/t km).

$PE_{y,power}$ estimated using small-scale CDM method AMS-III.L (UNFCCC, 2020a) (Equation 11).

$$PE_{y,power} = \sum_{k=1}^{K} EC_{k,y} \times EF_{k,y} \times (1 + TDL_{k,y}) \quad (11)$$

Descriptionn:

$PE_{y,power}$ = project emissions from electricity consumption in year y (t CO_2/year)

$EC_{k,y}$ = the amount of electricity consumed by the project

		from source k in year y (MWh/year)
$EF_{k,y}$	=	emission factor for electricity generated for source k y (t CO_2/MWh)
$TDF_{k,y}$	=	average technical transmission and distribution losses to provide electricity to source k in year y (%)
k	=	pyrolysis electricity consumption source

3. Potential Profit Receipt

The methods used are simple quantitative analysis and Profit Comparison Method (PCM). These two analyses measure the profit and potential revenue from pyrolysis products to determine the project's economic feasibility.

The simple quantitative analysis for revenue is formulated with Equation 12.

$$R_{y,b,l} = P_y \times 52 \times J_{y,b,l} \quad (12)$$

Description:

$R_{y,b,l}$	=	total revenue in year y with the combination of pyrolysis operation for b rounds of l working days (IDR/year)
P_y	=	product price in year y (IDR/liter/year),
$J_{y,b,l}$	=	number of products in year y with the combination of pyrolysis operation for b rounds of l working days per week (liter/year).

The PCM is formulated as per Equation 13 (Gotze et al., 2008):

$$U_{y,b,l} = R_{y,b,l} - C_{y,b,l} \quad (13)$$

Description:

$U_{y,b,l}$	=	profit in year y with the combination of pyrolysis treatment for b rounds of l working days (IDR/year)
$C_{y,b,l}$	=	total cost in year y with the combination of pyrolysis treatment for b rounds of l working days (IDR/year)

Estimated total cost (Equation 14).

$$C_{y,b,l} = CV_{y,b,l} + CF_{y,b,l} \quad (14)$$

Description:

$CV_{y,b,l}$	=	variable cost of the pyrolysis technology operation process (IDR/year)
$CF_{y,b,l}$	=	fixed cost of the pyrolysis technology operation process (IDR/year)

Fixed costs are estimated with Equation 15.

$$CF_{y,b,l} = CD_{y,b,l} + CT_{y,b,l} \quad (15)$$

Description:

$CD_{y,b,l}$	=	the depreciation cost of the tool in a certain period (IDR/year)
$CT_{y,b,l}$	=	cost of tools or assets for operating pyrolysis technology (IDR)

In order to calculate fixed costs, it is necessary to estimate depreciation costs according to Equation 16.

$$CD_{y,b,l} = \frac{CP_{y,b,l} - NS}{UE} \quad (16)$$

Description:

$CP_{y,b,l}$	=	total cost of purchasing technology or goods (IDR)
NS	=	project salvage value (IDR)
UE	=	economic life of the project (year)

RESULT AND DISCUSSION

Potential GHG Emissions Before the Project

Waste generated was estimated based on the data of waste generated by respondents every day and then accumulated for one community per year (Table 1). This study focuses on residual plastic waste, which is generally discarded directly, has no potential for recycling, and has no selling value, such as instant noodle packs, snacks, sachet drinks, crackle bags, soap and detergent packs, and bubble wrap.

The amount of plastic waste generated by households fluctuates every day. This increase in waste is even more evident with the COVID-19 pandemic, as people tend to

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shop online to reduce the time spent traveling outside the home and avoid crowds.

Emissions Before the Community Scale Pyrolysis Project
Baseline emissions were estimated from the emissions from the plastic waste generated by the Villa Tajur Community that was disposed of at the Galuga landfill and the transportation emissions of transporting waste from the community to the Galuga landfill (Table 2).

Table 1. Average community waste generated

Waste generated	Organic waste	Sanitary and diaper waste	Residual plastic waste	Recyclable waste	Total waste
Households (kg/day)	0.87	0.11	0.12	0.19	1.29
Villa Tajur Community (kg/day)	130.87	15.79	18.27	28.12	193.05
Villa Tajur Komunitas (ton/year)	47.77	5.76	6.57	10.26	70.46

Table 2. Baseline emissions in 2021

Emission sources	Emission produced (t CO_2e/year)
Waste generated	0.66
Transportation	3.04
Baseline emission	3.69

GHG emissions from waste generated at the Galuga landfill are related to waste dumped in the community and population growth. Meanwhile, emissions from waste transportation are generated from the motorized waste carts and trucks used to transport waste daily from the Villa Tajur Community to the Pasar Gembrong TPS. Subsequently, the waste is transported to the Galuga landfill.

GHG Emission Reduction Potential After the Community-Scale Pyrolysis Project
The development and introduction of pyrolysis technology have been widely carried out to reduce plastic waste piles and imperfect management or cause GHG emissions. Several communities have implemented pyrolysis technology with various capacities, ranging from 0.01 kg, 1 kg, 2 kg, to 20 kg. Generally, the technologies used by communities are only those with small capacity. In this study, the pyrolysis technology used as the research object has a capacity of 2 kg per round with the type of plastic waste used, namely LDPE and PP plastic or residual plastic. The community-scale pyrolysis technology is illustrated in Figure 1.

The location of the community-scale pyrolysis technology with a capacity of 2 kg was applied in one of the communities in RW 08, Sindangrasa Village, namely the Villa Tajur Community (see Figure 2); this is because the community is located near the city centers such as malls or shopping centers, hospitals, tourist attractions, grocery kiosks, and places of worship with urban community types so that the potential for plastic waste generated can be more significant. Therefore, reducing plastic from the source (household) is very necessary. Figure 3 shows the pyrolysis technology placement plan. The pyrolysis location was determined to utilize the vacant land in the Villa Tajur Community.

Emissions After the Project
Project emissions consist of 1) pyrolysis process emissions, 2) pyrolysis fuel usage, 3) waste transportation, and 4) electricity consumption. Project emissions depend on the fuel used and the frequency of pyrolysis operation days. This study estimated project emissions from three operationalization scenarios (Table 3) to see the potential of pyrolysis in reducing GHG emissions. The operationalization of pyrolysis technology

resulted in high project emission values compared to pre-project emissions (Table 4).

GHG Emission Reduction

GHG emission reduction is the difference between baseline emissions and pyrolysis project emissions. Table 5 shows the reduction potential of pyrolysis technology where there are negative and positive values. Harmful ER is indicated for pyrolysis that does not reduce emissions. Meanwhile, positive ER values indicate that pyrolysis can contribute to emission reduction.

Source: Marcelia (2013)

Figure 1. Example of community-scale pyrolysis technology

Figure 2. Location map of Villa Tajur community

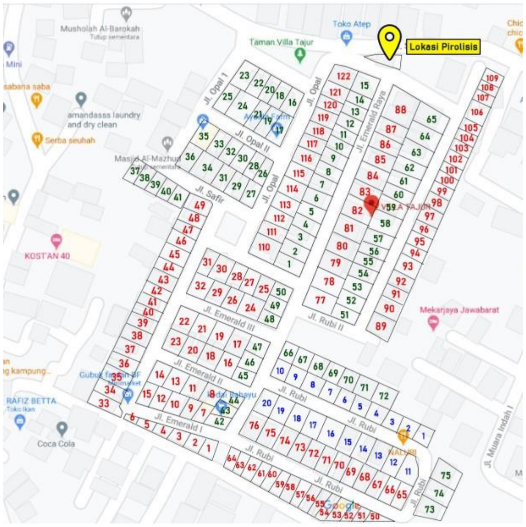

Figure 3. Pyrolysis technology implementation plan

Table 3. Operational scenario of community-scale pyrolysis technology

Scenario	Fuels	Frequency of Working Days (days)	Frequency of Turns (turns/day)
One	Firewood	5	3
Two	LPG	5	3
Three	Electricity	5	3

Table 4. Project emissions in 2021

Scenario	PE Pyrolysis Process (t CO_2e/year)	PE Fuels (t CO_2e/year)	PE Carrier Transportation (t CO_2e/year)	PE Electricity Consumption (t CO_2e/year)	Total PE (t CO_2e/year)
Satu	1.58	725.09	0.07	0.05	726.78
Dua	1.58	5.27	0.07	0.05	6.97
Tiga	1.58	0	0.07	1.59	3.23

Table 5. GHG emission reduction potential in 2021

Scenario	Baseline Emission (BE) (t CO_2e)	Emission Project (PE) (t CO_2e)	Emission Reduction (ER) (t CO_2e)	Emission Reduction Percentage (PER) (t CO_2e)
	(a)	(b)	(c) = (a)-(b)	(d) = (c)/(a)*100%
One	3.69	726.78	-723.09	-19.571%
Two	3.69	6.97	-3.27	-89%
Three	3.69	3.23	0.46	13%

To illustrate the long-term emission reduction potential, the difference between baseline and project emissions is projected for 2030. This shows the potential contribution of pyrolysis technology in reducing GHG emissions by Indonesia's commitment of 29% by 2030 (Sugiyono, 2006; KLHK, 2017).

Figure 4 shows that project emissions from scenario one in 2030 are predicted to increase to 726.80 t CO_2e. This is due to wood fuel, which causes additional GHG emissions. Although from an economic perspective, it can reduce operational costs because it utilizes wood waste in the community, there is a trade-off so that the use of firewood is currently irrelevant.

In scenarios two and three, the pyrolysis project emissions significantly decrease (see Figure 5). The estimated emissions from scenario two amounted to 6.99 t CO_2e, and scenario three amounted to 3.25 t CO_2e.

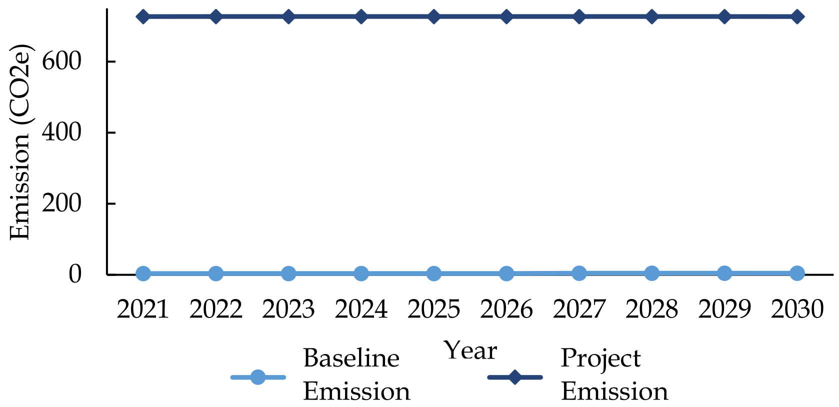

Figure 4. Baseline emissions and scenario one pyrolysis project emissions 2021-2030

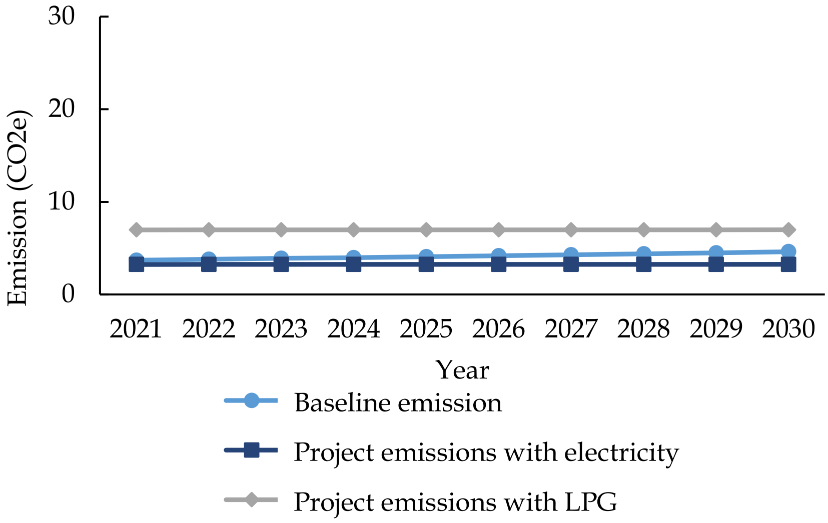

Figure 5. Combination of scenario two and three baseline emissions and pyrolysis project emissions in 2021-2030

Based on calculating project emissions from the three scenarios, scenario three produces the lowest project emissions; this means that scenario three can reduce emissions by 0.46 t CO_2e (13%) to 1.36 t CO_2e (30%) in 2021-2030. Thus, community-scale pyrolysis that utilizes electrical energy with a particular operational frequency has the potential to be implemented.

Potential Revenue and Profit of Community-Scale Pyrolysis Products

Revenue comes from selling pyrolysis products in liquid fuels equivalent to kerosene and gasoline (Naufan, 2016; Liestiono et al., 2017). This study only estimates pyrolysis with electric fuel, which has the potential to reduce GHG emissions (see Table 6). The pyrolysis process produces the same amount of product, namely 0.26 liters/turnover, which refers to Pani et al. (2017).

The pyrolysis operation requires costs, the components of which consist of fixed and variable costs. The details of these costs are shown in Table 7.

In the investment of a project, technology and equipment or assets have the potential to depreciate every year. As with the community-scale pyrolysis project, the depreciation costs of the technology and equipment are shown in Table 8.

The depreciation cost per year determines the fixed cost for one year. The estimation results are used to calculate the total operational cost per year. Hence, the operating cost for one year is shown in Table 9.

The total cost of pyrolysis operation affects profitability. Table 9 shows that pyrolysis technology investment is not profitable and does not achieve absolute or relative profitability (UNFCCC, 2020a).

Pyrolysis technology can support the Bogor program without plastic bags (BOTAK). In addition to banning plastic bags, reducing plastic from its source can be a solution to achieving the program. Thus, applying community-scale pyrolysis technology with a capacity of 2 kg can provide two benefits: plastic waste reduction and GHG emission reduction (Table 9).

Private companies also have the potential to help overcome the cost deficit through Corporate Social Responsibility (CSR) programs or technology grants. Thus, the existence of this program can help reduce the cost burden and provide new insights for the community.

Community members can also contribute to overcoming the operational fund deficit. The first way can involve residents in running the pyrolysis process from waste collection to pyrolysis operation. The second way is by allocating monthly community cash or collecting self-help funds from each resident. Third, residents can propose applying pyrolysis technology to the urban village. This proposal will be submitted during the development plan meeting (Musrembang) with the sub-district. If approved, it can provide the community with funds for pyrolysis operations..

The involvement of multiple parties can realize the application of pyrolysis that positively impacts efforts to prevent climate change and plastic waste. So, the community is interested in implementing pyrolysis technology with a capacity of 2 kg. In that case, it can use electrical energy fuel with operating time every five days/week because it has been proven environmentally and economically feasible even though it requires other parties as donors. This study empirically strengthens the idea of implementing community-scale pyrolysis technology in reducing GHGs, provided that the technology uses electrical energy. Previously, Wijayanti (2020) analyzed the potential technical and financial feasibility of community-scale pyrolysis technology with a capacity of 5 kg fueled by LPG and showed a higher potential annual revenue of IDR12,000,0000.00 per year, but it was not environmentally feasible. The technology could increase GHG emissions by 1.44 t CO_2e/year. In addition, Ardianti et al. (2019) also examined pyrolysis with a capacity of 4 kg, showing that the pyrolysis product reached 1.8 to 2 liters/turn. Meanwhile, Sirait et al. (2020) produced 4 liters of liquid fuel from a pyrolysis reactor with a capacity of up to 75 kg using an input of 5 kg plastic. The amount of pyrolysis capacity affects plastic waste reduction efforts, pyrolysis product revenue, and GHG emissions. To confirm the feasibility of pyrolysis technology in reducing GHG emissions and increasing revenue, further research can be conducted on estimating the potential of pyrolysis by expanding the project capacity. However, this research needs to be developed to determine the feasibility of using pyrolyzed oil in vehicles to reduce GHG emissions; this is because the pyrolysis process triggers carbon monoxide (CO), nitrogen dioxide (NOx), and hydrocarbon

(HC) emissions. Therefore, further research is needed from an environmental and economic aspect as a consideration for those who will use pyrolysis oil.

Table 6. Alternative pyrolysis product acceptance

Alternative	Number of working days (day)	Number of turns (turns/day)
One	5	3
Two	6	3
Three	7	3

Table 7. Cost breakdown of community-scale pyrolysis operationalization per year

Cost component	Unit	Total (unit)	Cost Per Unit (IDR)	Total Cost (IDR)
		(a)	(b)	(c)=(a)*(b)
Fixed coat:				
Pyrolysis Assembling	Unit	1	958,868	958,868
Thermo control	Unit	1	450,000	450,000
Transformator 50 A	Unit	1	446,000	446,000
Supporting equipment:				
Bucket	Unit	3	15,000	45,000
Basin	Unit	2	22,500	45,000
Water hose	Unit	1	45,000	45,000
Total fixed costs				1,989,868
Total fixed costs:				
Electricity	Package/month		60,000	720,000
Gasoline Vehicle	Package/month		50,000	2,600,000
Labor	Person	2	500,000	12,000,000
Total variable cost				15,320,000

Table 8. Depreciation cost of pyrolysis operation

Cost Component	Economic life (year)	Total cost (IDR)	Remaining Value (IDR)	Depreciation Cost (IDR/year)
	(a)	(b)	(c)=20%*(b)	(d)=(b)-(c)/(a)
Pyrolysis Assembling	5	958,868	191,774	153,410
Thermo control	3	450,000	90,000	120,000
Transformator 50 A	5	446,000	89,200	71,360
Bucket	1	45,000	9,000	36,000
Basin	1	45,000	9,000	36,000
Water hose	1	45,000	9,000	36,000
Total				452,779

Table 9. The ratio of revenue to pyrolysis operating cost per year

Alternatives	Emission Reduction (t CO_2e)	Acceptance (IDR/year)	Operational Cost (Rp/year)	Profit (Rp/year)	Ratio of revenue to the total cost (%)
		(a)	(c)	(e)=(a)-(b+c)	(d)=(a)/(b)*100%
One	0.46	1,014,000	15,772,779	-14,758,779	6.43
Two	-0.17	1,216,800	15,904,779	-14,890,779	7.65
Three	-0.81	1,419,600	16,048,779	-15,034,779	8.85

CONCLUSION

The Villa Tajur community generates 0.12 kg/day or 6.27 tons/year of residual plastic waste. Regarding the project boundary, emissions before the project in 2021-2030 amounted to 3.69 t CO_2e to 4.61 t CO_2e. After the project, emission reduction is achieved if pyrolysis uses fuel in electrical energy, with a potential decrease in 2021-2030 from 13% to 30%. This study shows that pyrolysis technology is considered unprofitable or not economically feasible because the operational costs exceed the revenue. However, regarding environmental benefits, pyrolysis technology can reduce emissions and plastic waste generated in the long term. Therefore, this technology can be implemented if provided with grants.

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