



## Assessing the Environmental Impacts of Banana Farming in Yogyakarta Special Region Using Life Cycle Assessment (LCA)

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### ABSTRACT

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*Life Cycle Assessment, banana cultivation, environmental awareness, sustainable agriculture, organic fertilizers*

Indonesia is one of the largest banana producers in Asia, with an annual production of 9.34 million tons, including 809,976 quintals from Yogyakarta in 2022, making banana cultivation an important sector. This study evaluates the environmental impact of banana cultivation in the Special Region of Yogyakarta using the Life Cycle Assessment (LCA) approach with the IMPACT 2002+ method. The research sample involved 80 farmers and 4 distributors from two main regions. The analysis focused on four main categories: human health, ecosystem quality, climate change, and resource consumption, which are the core elements of the IMPACT 2002+ method. Farmers' environmental awareness was assessed based on seven indicators, including land and water management, as well as the use of fertilizers and pesticides. The results showed that NPK fertilizer is the main contributor to climate change, accounting for 92.3% of greenhouse gas emissions (4.48E4 kg CO<sub>2</sub> eq). A shift to organic fertilizers is estimated to reduce emissions by up to 30%. Meanwhile, distribution activities accounted for 87.3% of resource consumption (6.07E5 MJ primary) due to the use of fossil fuels. These findings highlight the importance of transitioning to sustainable practices, such as the use of organic fertilizers and optimizing local distribution networks. This study provides a basis for agricultural policies that support ecosystem balance and climate change mitigation.

## 1. INTRODUCTION

Bananas are one of the most popular types of horticultural plants worldwide [1]. Every part of the banana plant can be processed, including the fruit and peel, into products such as banana chips, banana flour, banana biscuits, it can most commonly be consumed directly [2]. Bananas are plants that thrive in tropical and subtropical regions [3] such as Indonesia, Malaysia, South America, and Central America. As the largest banana producer in Asia, accounting for 50% of Asia's banana production [4].

As the largest banana producer in Asia, Indonesia also has a high domestic demand for this fruit. Bananas are popular and widely consumed by people in Indonesia. Household banana consumption in Indonesia increases yearly. According to the Central Statistics Agency, in 2023, household banana consumption reached 2.37 million tons [5], with banana production in Indonesia amounting to 9.34 million tons.

One of the main banana-producing provinces in Indonesia is the Special Region of Yogyakarta. According to the Central Statistics Agency, banana production in Yogyakarta in 2022

reached 809,976 quintals. These figures are a calculation of the total production across all regencies in the Special Region of Yogyakarta. This high level of production directly impacts the community economically, socially, and environmentally [6]. Additionally, banana cultivation has positive environmental effects, such as preventing soil erosion and enhancing soil fertility [7]. However, farming activities inevitably involve the use of fertilizers and pesticides to increase crop yields [8]. Continuous and improper use of these inputs can have adverse effects. The use of fertilizers and pesticides constitutes a significant input in agricultural activities, particularly fertilizers and pesticides that contribute to increasing CO<sub>2</sub> levels, which impact greenhouse gas emissions, as well as damage soil and cause water pollution that can harm human health and natural resources [9]. Other environmental inputs include farming activities such as land preparation, planting, weeding, harvesting, post-harvest processes, and distribution. These activities contribute to increased CO<sub>2</sub> levels, which lead to the accumulation of greenhouse gases and impact the atmosphere [10].

Nevertheless, the environmental impact of banana farming

activities is not widely recognized by farmers, including those in Yogyakarta [11]. Increasing environmental awareness among farmers can help mitigate these impacts by reducing the use of chemical inputs [12].

Therefore, this study aims to analyze the environmental impacts of banana farming in Yogyakarta and assess farmers' awareness of the environmental effects resulting from their agricultural activities. Using the Life Cycle Assessment method to evaluate the environmental impact of banana farming allows for an assessment of all environmental effects, including impacts on human health, ecosystem quality, climate change, and resources. The results can then be used as an evaluation tool for both banana farmers and agricultural policymakers to reduce the environmental impacts of banana farming in the Special Region of Yogyakarta [13].

## 2. RESEARCH METHOD

### 2.1 Research location

The research locations shown in Figure 1 were purposively selected in Badongan District, Semin Village, Gunung Kidul Regency, and Samiran District, Parangtritis Village, Bantul Regency. Both locations are situated in the Special Region of Yogyakarta. This selection was based on the consideration that the majority of the community in these areas is composed of banana farmers. Additionally, another aspect of the location selection was to analyze the environmental impacts of banana cultivation activities in these two areas.

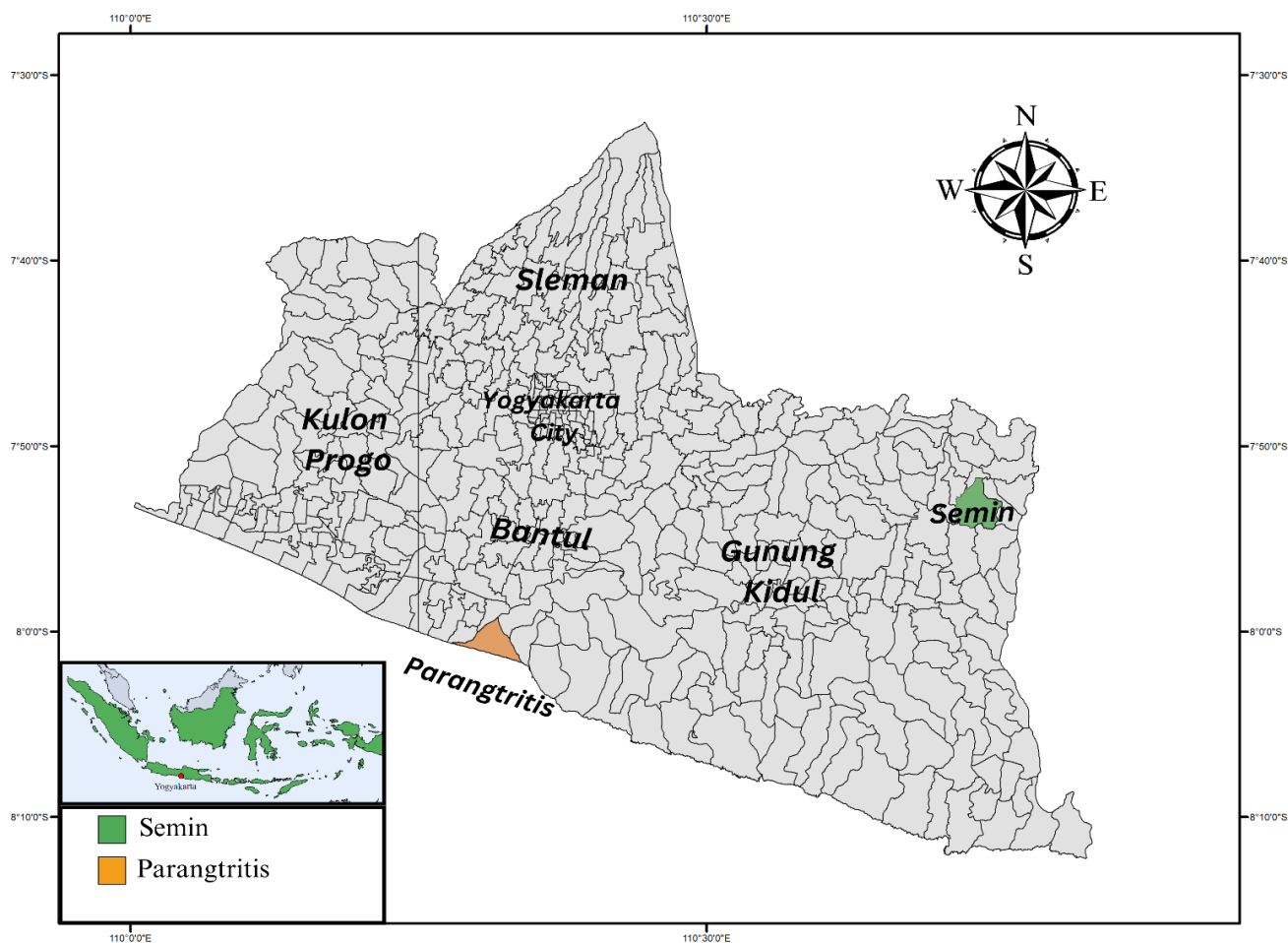


Figure 1. Research location

### 2.2 Sampling procedure and data collection

The data for this study were obtained through interviews with 84 individuals, including 80 banana farmers and 4 traders or distributors from the two locations (Table 1). This data was collected to understand all farming activities as well as the distribution distances from farmers to middlemen or large-scale traders.

Interviews with farmers were conducted using questionnaires that directly inquired about all inputs in banana farming, such as seeds, fertilizers, pesticides, machinery usage, and fuel consumption, including their respective volumes.

Additionally, questions related to environmental awareness were also included, covering 7 environmental awareness indicators. Meanwhile, traders or distributors were only asked about their distribution distances to determine fuel usage in distribution activities.

Table 1. Type and number of samples

Respondent	Badongan Village	Samiran Village
Farmer	40	40
Trader/Distributor	2	2
<b>Total</b>	<b>42</b>	<b>42</b>

### 2.3 Framework of thought

The framework in Figure 2 illustrates the analysis process using Life Cycle Assessment (LCA), starting from land preparation through post-harvest and distribution. Dashed lines are used to represent the distribution distance, as only fuel inputs for distribution are analyzed. Additionally, an analysis

was conducted on banana farmers based on seven indicators: knowledge of environmental impacts, land management, water management, fertilizer and pesticide use, conservation of biodiversity and habitats, environmental education and support, and future goals. This analysis focuses on the impacts of banana farming on human health, ecosystem quality, climate change, and resource use.

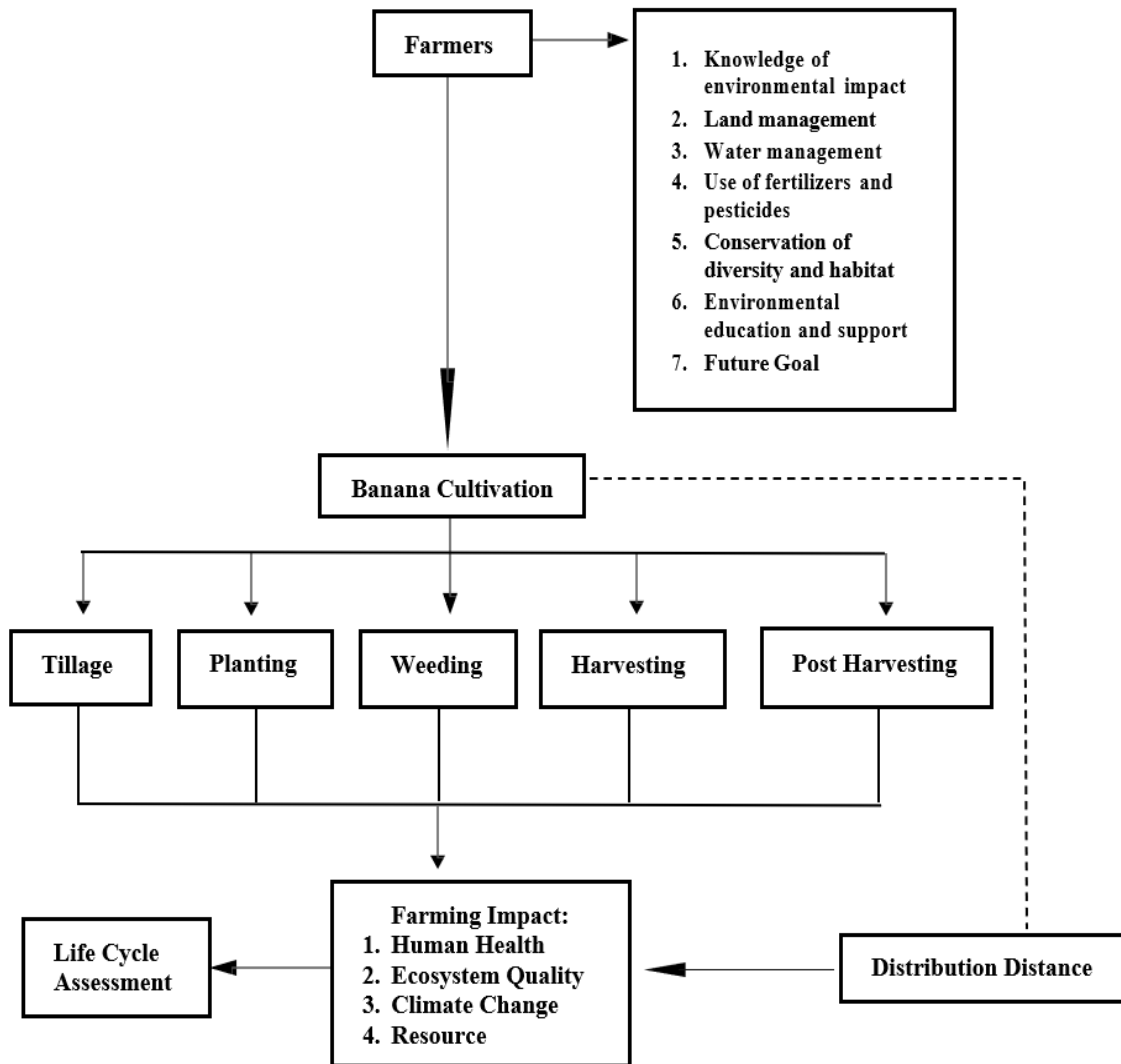


Figure 2. Framework

### 2.4 Analytical technique

The research method employed is a descriptive quantitative approach. This quantitative approach involves collecting data through surveys, experiments, and testing [14]. It is linked to research variables focusing on current issues and phenomena, with results presented in meaningful numerical forms [15]. The descriptive method involves gathering existing information, explaining it with specific objectives, planning the approach, and collecting data to provide an accurate and clear description of a phenomenon, situation, or group [16]. The Life Cycle Assessment (LCA) analysis, used to determine the environmental impact of banana farming in the Special Region of Yogyakarta, employed the SimaPro application with the IMPACT 2002+ method. This aligns with the framework to assess impacts or damage in four categories: human health,

ecosystem quality, climate change, and resources. This model can be applied to systems that have comprehensive input-output data across all stages of the life cycle, from production to distribution. This model is particularly suitable for agricultural systems as it allows for the quantification of emissions from chemicals (such as fertilizers and pesticides), fuel usage, and land use changes. The IMPACT 2002+ model has been widely used in international studies to evaluate agricultural systems and industries with international standards, such as ISO 14040 and ISO 14044, which define the principles and guidelines for Life Cycle Assessment of products and processes [17]. For environmental awareness analysis, the Spearman Rank correlation was used to examine the relationship between seven indicators of environmental awareness and farmer characteristics, including age, land size, education level, and income.

### 3. RESULT AND DISCUSSION

#### 3.1 Characteristics of farmers

Background information on the social and economic aspects of banana farmers in the Special Region of Yogyakarta, which could potentially influence their awareness of environmental impacts [18]. These characteristics include age, income, education level, and land size.

In Figure 3 of banana farmers' ages, the largest group, aged 46-55 years, accounts for 38.78% of the total. This age group is still considered productive as most individuals still possess sufficient physical ability to manage agricultural land [19, 20], although there is a decline in stamina compared to the 20-40 age group [21]. However, farmers in this age group often have better experience and knowledge compared to younger farmers, which can enhance work efficiency [22].

In terms of income, 43% of banana farmers earn between IDR 800,000 and IDR 1,500,000 (Figure 4). This is categorized as low income [23], considering that the regional minimum wage (UMR) across all regencies in the Special Region of Yogyakarta exceeds IDR 2,100,000. This indicates that farmers' earnings are still insufficient to be considered prosperous or to meet the established minimum income standards.

Most banana farmers in the Special Region of Yogyakarta have a high school education, with over 50% reaching this level, accounting for 42 farmers (Figure 5). This indicates a high awareness of formal education and reflects the availability of adequate educational facilities. A higher level of education facilitates the absorption of knowledge and technology, both in the agricultural sector and other fields [24, 25].

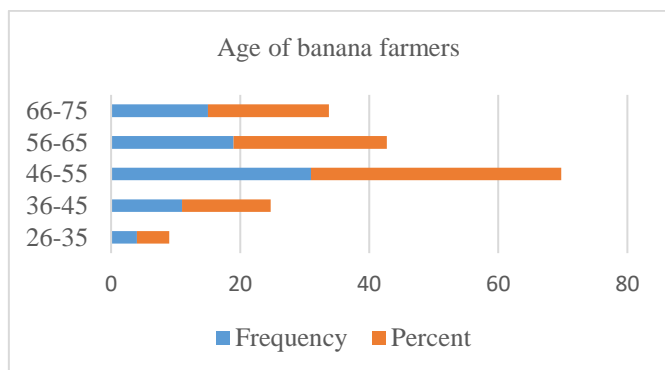


Figure 3. Age data of banana farmers

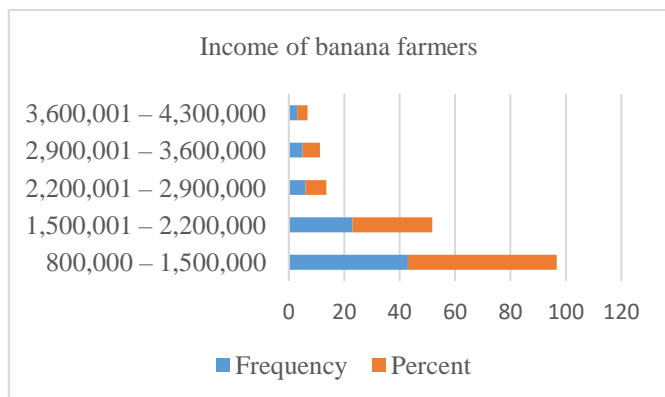


Figure 4. Income data of banana farmers

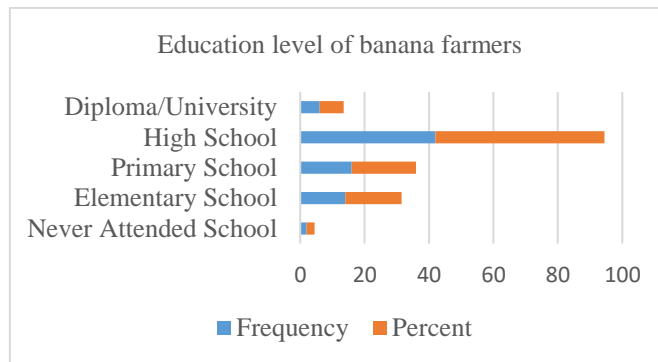


Figure 5. Educational level data of banana farmers

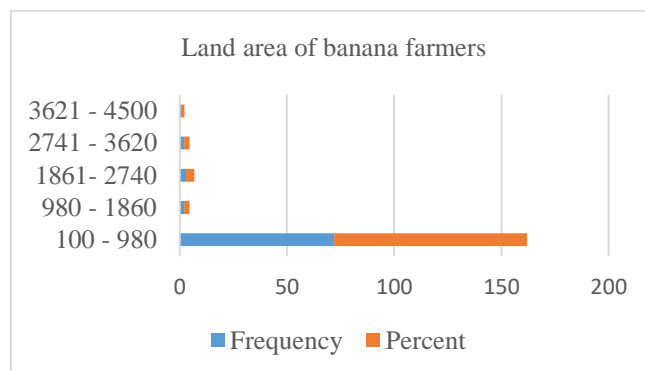


Figure 6. Land area data of banana farmers

Land size is the most significant factor influencing the income of banana farmers [26]. In the special region of Yogyakarta, 90% of banana farmers own land between 100m<sup>2</sup> and 980m<sup>2</sup> (Figure 6). This size falls into the category of being less than ideal for commercial farming [27]. Such land sizes are more suitable for subsistence farming, which primarily meets the needs of the farmer's family. With this limited land area, farmers can only produce enough food for daily consumption, making it challenging to achieve a surplus for market sale [28].

#### 3.2 Farmers' environmental awareness

##### 3.2.1 Environmental awareness

Farmers' environmental awareness is crucial as it directly relates to the conservation of natural resources, agricultural sustainability, and their long-term well-being [29]. In Table 2, it can be seen that the awareness of banana farmers towards the environment, categorized as good, is reflected in the average total score of 4.55 for all environmental awareness indicators. This figure indicates a high level of awareness among farmers, which is based on the fact that these indicators are fundamental for the implementation of sustainable farming practices.

Table 2. Environmental awareness of banana farmers

Indicator	Score	Category
Knowledge of environmental impact	4.56	Good
Land management	4.59	Good
Water management	4.47	Good
Use of fertilizers and pesticides	4.66	Good
Conservation of diversity and habitat	4.64	Good
Environmental education and support	4.40	Good
Future Goal	4.57	Good
<b>Total</b>	<b>4.55</b>	<b>Good</b>

**Table 3.** Correlating factors

		Age	Edu.	Income	Land
<b>Knowledge of Environmental Impact</b>	Correlation Coefficient	.155	-.095	-.103	.166
	Sig. (2-tailed)	.171	.400	.361	.141
	N	80	80	80	80
<b>Land Management</b>	Correlation Coefficient	.152	-.015	.050	.077
	Sig. (2-tailed)	.177	.892	.661	.496
	N	80	80	80	80
<b>Water Management</b>	Correlation Coefficient	.006	.078	.077	.102
	Sig. (2-tailed)	.958	.492	.499	.370
	N	80	80	80	80
<b>Use of Fertilizers and Pesticides</b>	Correlation Coefficient	-.038	-.004	-.137	.068
	Sig. (2-tailed)	.738	.973	.227	.550
	N	80	80	80	80
<b>Conservation of Diversity and Habitat</b>	Correlation Coefficient	-.125	.091	.088	.014
	Sig. (2-tailed)	.268	.421	.435	.900
	N	80	80	80	80
<b>Environmental Education and Support</b>	Correlation Coefficient	.231*	-.101	.112	.074
	Sig. (2-tailed)	.039	.374	.322	.513
	N	80	80	80	80
<b>Future Goal</b>	Correlation Coefficient	.025	-.061	.040	-.153
	Sig. (2-tailed)	.825	.589	.722	.175
	N	80	80	80	80

Although the environmental awareness of banana farmers is generally considered good, the level of implementation of environmentally friendly practices for each indicator still needs improvement. More intensive training and mentoring programs, support for environmentally friendly technology, and government policies that promote sustainable agriculture are crucial to ensure that this awareness can be translated into practical actions. This will have a positive impact not only on the environment but also on the social and economic sustainability of the farmers [30].

### 3.2.2 Correlated factors

Correlation analysis between farmer characteristics and environmental awareness in this study used the Spearman Rank method to determine the relationship between all variables and to ensure the correlation coefficient for this relationship [30, 31]. Table 3 shows a correlation between education and environmental support with environmental awareness. A higher level of education is strongly related to increased environmental awareness. Farmers with higher education are more likely to have good environmental knowledge and have positive habits towards the environment [32].

## 3.3 Environmental impact assessment

### 3.3.1 Network

Network, used to determine the relationship of banana cultivation activities that impact the environment. Red lines will indicate the influence on environmental impact, the thicker the red line will indicate the greater the influence exerted. Referring to Figure 7, it shows that the largest input is in the planting activity with an NPK fertilizer input of 14.47 Pt. NPK (Nitrogen, Phosphorus, Potassium) fertilizer is a fertilizer commonly used in agriculture to increase crop yields.

However, excessive use of NPK fertilizer can have negative impacts on the environment. Nitrogen-based fertilizers, especially in large amounts, can produce greenhouse gases such as nitrous oxide (N<sub>2</sub>O), which has a much greater global warming potential than carbon dioxide (CO<sub>2</sub>) [33].

### 3.3.2 Characterization

In Table 4, this stage refers to the process of quantifying and categorizing the potential effects of banana farming activities. This stage is a follow-up step in data processing to determine the environmental impacts generated from raw materials, inputs, and energy. In this stage, 15 categories of environmental impact will be displayed. The characterization table presents an evaluation of the environmental impacts of banana farming activities based on various impact categories. Each category indicates the amount of emission contribution or resource usage in specific units related to certain environmental aspects. This table shows that harvesting activities are the main contributors to most environmental impact categories, including global warming, ecotoxicity, acidification, and eutrophication. The use of diesel provides a small but still significant additional impact in various categories. Therefore, to reduce the environmental impact of banana farming, it is necessary to optimize the harvesting process and adopt more environmentally friendly energy solutions.

### 3.3.3 Damage assessment

At this stage, the analysis can be used to consider ways to improve environmental impacts. This stage aims to group several indicators from the characterization stage into four damage categories. These categories are human health, ecosystem quality, climate change, and resources. Table 5 shows the main activities that are the primary contributors to all damage categories, namely harvesting activities, followed by the use of diesel post-harvest, which contributes minimally but still impacts each category. Therefore, efforts to reduce environmental impacts should focus on optimizing the harvesting process and utilizing more environmentally friendly energy sources. One of the impacts is on human health, measured in DALYs. DALY is a measure of disease burden, where one DALY is equivalent to one year of healthy life lost [34]. The greatest impact was found during the harvesting stage, amounting to 0.0374 DALYs.

### 3.3.4 Normalization

The normalization stage involves standardizing the units of all damage categories. This standardization is done after the damage assessment process to facilitate analysis across different environmental impact categories. The results in Table 6, the normalization stage, do not have units because this stage is about standardizing the units from all units produced in the damage assessment stage.

### 3.3.5 Weighting

Weighting is the stage where all assessed impacts are simplified and compared using the same unit of measurement so that results can be obtained according to their level of importance. In Table 7, it is known that the total damage to the environment from banana cultivation in DIY is 14.7 Pt. In the human health category, the value is 5.27 Pt. The unit of measurement at this stage is Point (Pt), where a scale of 1 Pt represents one thousandth of the annual environmental burden on one average European.

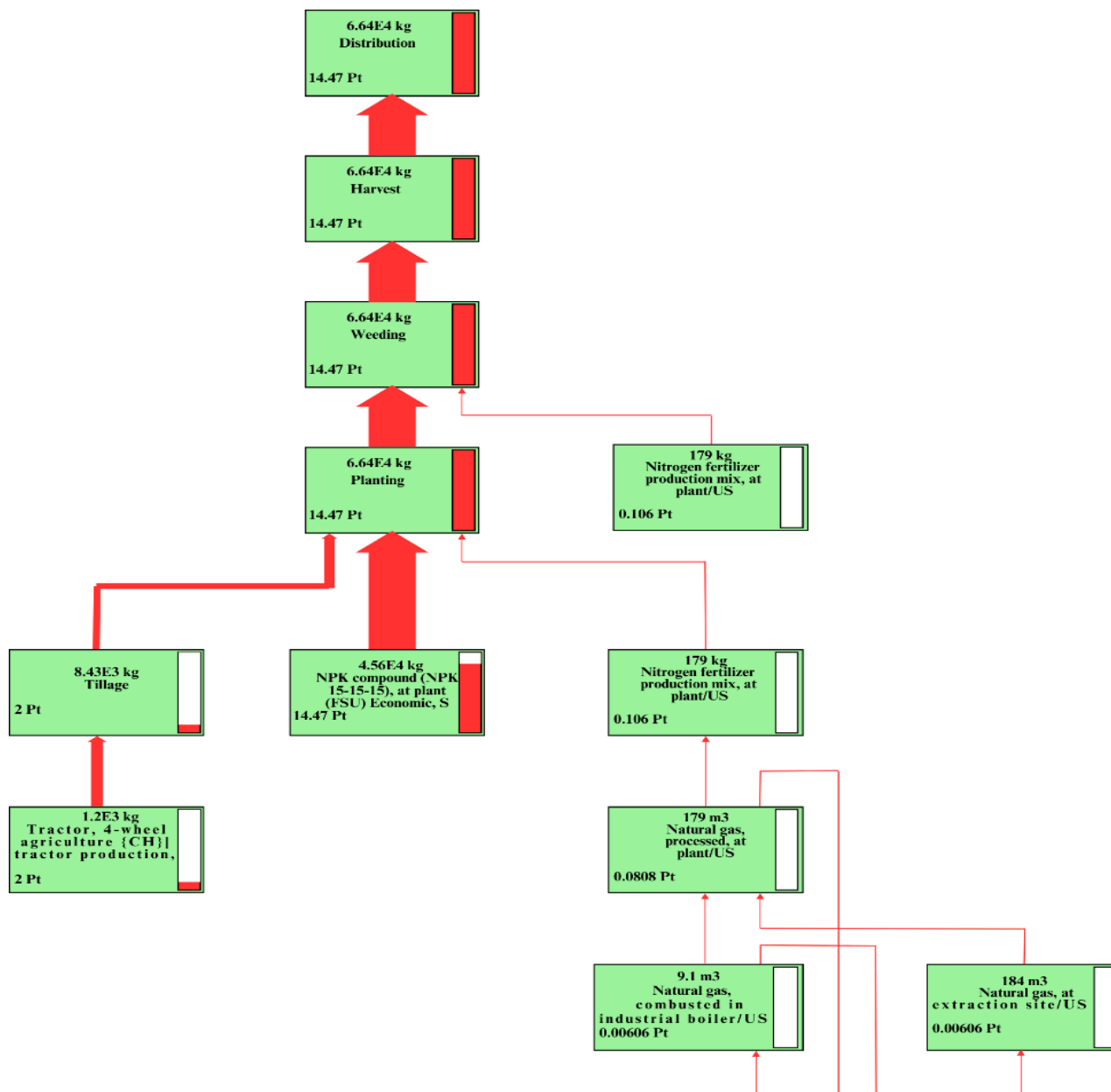


Figure 7. Network analysis of banana farming

Table 4. Characterization of banana farming

Impact Category	Unit	Total	Distribution	Harvest	Dummy_Gasoline Used in Personal Vehicle	Diesel {CH} Market for Diesel
Carcinogens	kg C <sub>2</sub> H <sub>3</sub> Cl eq	2.10E+03	x	2.10E+03	x	0.0571
Non-carcinogens	kg C <sub>2</sub> H <sub>3</sub> Cl eq	2.75E+03	x	2.75E+03	x	0.188
Respiratory inorganics	kg PM <sub>2.5</sub> eq	33.8	x	33.8	x	0.0154
Ionizing radiation	Bq C-14 eq	1.55E+05	x	1.55E+05	x	61.9
Ozone layer depletion	kg CFC-11eq	0.00319	x	0.00319	x	1.97E-06
Respiratory organics	kg C <sub>2</sub> H <sub>4</sub> eq	28.3	x	28.2	x	0.146
Aquatic ecotoxicity	kg TEG water	4.91E+06	x	4.91E+06	x	327
Terrestrial ecotoxicity	kg TEG soil	1.45E+06	x	1.45E+06	x	219
Terrestrial acid/nutri	kg SO <sub>2</sub> eq	581	x	581	x	0.317
Land occupation	m <sup>2</sup> org.arable	592	x	592	x	0.282
Aquatic acidification	kg SO <sub>2</sub> eq	249	x	249	x	0.0813
Aquatic eutrophication	kg PO <sub>4</sub> P-lim	2.57	x	2.57	x	0.00182
Global warming	kg CO <sub>2</sub> eq	4.48E+04	x	4.48E+04	x	20.8
Non- renewable energy	MJ primary	6.01E+05	x	6.01E+05	x	25.6
Mineral extraction	MJ surplus	6.08E+03	x	6.08E+03	x	0.172

**Table 5.** Damage assessment banana farming

Damage Category	Unit	Total	Distribution	Harvest	Dummy_Gasoline Used in Personal Vehicle	Diesel {CH} Post Harvest
Human health	DALY	0.0374	x	0.0374	x	1.18E-05
Ecosystem quality	PDF*m <sup>2</sup> *yr	1.30E4	x	1.30E4	x	2.38
Climate change	kg CO <sub>2</sub> eq	4.48E4	x	4.48E4	x	20.8
Resources	MJ primary	6.07E5	x	6.07E+05	x	25.7

**Table 6.** Normalization banana farming

Damage Category	Unit	Total	Distribution	Harvest	Dummy_Gasoline Used in Personal Vehicle	Diesel {CH} Post Harvest
Human health		5.27	x	5.27	x	0.00167
Ecosystem quality		0.949	x	0.949	x	0.000174
Climate change		4.53	x	4.53	x	0.0021
Resources		3.99	x	3.99	x	0.000169

**Table 7.** Weighting banana farming

Damage Category	Unit	Total	Distribution	Harvest	Dummy_Gasoline Used in Personal Vehicle	Diesel {CH} Post Harvest
Total	Pt	14.7	x	14.7	x	0.00411
Human health	Pt	5.27	x	5.27	x	0.00167
Ecosystem quality	Pt	0.949	x	0.949	x	0.000174
Climate change	Pt	4.53	x	4.53	x	0.021
Resources	Pt	3.99	x	3.99	x	0.000169

### 3.3.6 Interpretation

After going through all the stages of the Life Cycle Assessment (LCA) analysis and seeing the largest input. Regarding the environment as shown in Figure 7, the input of NPK fertilizer has the greatest impact on the environment from banana farming activities in the Special Region of Yogyakarta. In addition to the use of NPK fertilizer during planting, distribution activities also contribute significantly with fuel inputs in the form of gasoline and diesel, as well as the use of vehicles such as motorcycles and cars. In an effort to reduce the environmental impact of banana farming activities, it can be started by reducing the use of chemical fertilizers and cultivating the use of organic fertilizers to support sustainable agriculture and maintain soil fertility [34, 35]. Organic fertilizers are relatively easy to make on one's own [36], but due to the high use of chemical fertilizers, organic fertilizers have not been effective because the soil has become dependent on chemical fertilizers [37].

Therefore, soil regeneration can be done by mixing the use of chemical fertilizers and organic fertilizers [38] by increasing the dose of organic fertilizer in each application so that the soil becomes accustomed to organic fertilizers [39]. Soil that is accustomed to the use of organic fertilizers will be much more fertile and good for the long term than soil that uses chemical fertilizers which can damage the soil in the long term [40].

## 4. CONCLUSION

This study demonstrates that banana cultivation in the special region of Yogyakarta has significant environmental impacts. Particularly from the use of NPK fertilizers and the distribution of harvested products. Analysis using the Life

Cycle Assessment (LCA) method with IMPACT 2002+ identified that NPK fertilizers are the main contributor in the climate change category. From Table 5, the total climate change impact is 4.48E4 kg CO<sub>2</sub> eq, with the largest impact coming from NPK fertilizers used during the planting phase. Based on network analysis, NPK fertilizers account for the majority of this impact. In the Table 7, the climate change category has a total weight of 4.53 Pt, mostly attributed to emissions from NPK fertilizers. Thus, NPK fertilizers contribute 92.3% of the total greenhouse gas emissions impact.

On the other hand, distribution contributes additional greenhouse gas emissions through the use of fossil fuels such as gasoline and diesel. However, its contribution is smaller compared to the impact of fertilizers. In the resources category, from Table 5, resource consumption reaches 6.07E5 MJ primary. In Table 7, the total weight for resources is 3.99 Pt, with distribution contributing significantly due to the use of transportation fuels. Therefore, the use of fossil fuels in distribution contributes 87.3% to resource consumption and air pollution.

From a farmer's perspective, although their environmental awareness is considered good, there are challenges in implementing more environmentally friendly practices. The long-standing habit of using chemical fertilizers and limited access to organic fertilizers are major obstacles in reducing negative environmental impacts. However, the analysis results show that soil regeneration by combining chemical and organic fertilizers can be an effective solution. This step not only gradually improves soil fertility but also supports sustainable agricultural practices.

This research also highlights the importance of education and training related to environmentally friendly agriculture. Higher formal education is significantly correlated with increased awareness and positive behavior towards



environmental conservation. Therefore, continuous training and technical assistance are needed to encourage the transition to more sustainable agricultural practices.

Overall, this research provides important insights for stakeholders in the agricultural sector, particularly in developing policies that support the use of sustainable agricultural technologies. The implementation of organic fertilizer subsidy policies, strengthening local distribution networks, and environmental awareness campaigns can help reduce the environmental impact of banana cultivation while improving farmers' welfare. With these steps, it is hoped that the agricultural sector can contribute positively to ecosystem sustainability and climate change control.

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