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Estimation of Eco-Efficiency of Wastewater Management Plants Using the *Life Cycle Assessment (LCA) Method*

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Abstract

An eco-cost measurement was carried out to see the LCA process stages' efficiency in this study. The LCA process used in the wastewater treatment plant will carry out the steps in the LCA method. The four phases must be carried out correctly to provide good results when making decisions for improvements in each process unit carried out. When carrying out goals and scope, the process determines the goals to be achieved in wastewater management. Environmental impact calculations are carried out using SimaPro software. The nine types defined by the abbreviation are climate change or global warming potential (GWP), freshwater eco-toxicity potential (FETP), freshwater eutrophication potential (FEP), human toxicity potential (HTP), metal depletion potential (MDP), depletion ozone potential (ODP), particulate matter formation (PMF), terrestrial eco-toxicity potential (TETP), and water depletion potential (WDP). The value of the Eco-Efficiency Index (EEI) in the wastewater management installation is 0.183.Meanwhile, the Eco-Efficiency Ratio (EER Rate) value in the installation is -445.81% The total damage assessment resulting from the process is human health (DALY) of 0.00339, ecosystem quality (PDF m^2yr) of 874,123 and resources (MJ Surplus) of 5,8234. Then the eco cost value for human health is IDR 4,293,393.642; ecosystem quality is IDR 20,944,494.07; land resources is IDR 409,629. Then the Eco-Efficiency Index (EEI) value in the wastewater management installation is 0.178. Thus the installation can be affordable (financially affordable) and not sustainable (not environmentally friendly) because the eco cost value is greater than the net value of the WWTP.

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Introduction

The people living in the Muara Enim River area have long used the water flowing along the Muara Enim River. Many impacts or effects resulted from river water use along the Muara Enim River [1]. Therefore there is an initiative from the residents who live along the Muara Enim River. They have planned a communal management installation [2]. This collaborative wastewater treatment is a community's joint effort and forms an agreement to build the wastewater management installation. Some of the community did not participate in this activity. However, almost 80% of community members have participated in this activity. Community members are willing to use the land to manage wastewater management and implement this wastewater management. Wastewater discharged from community households is specifically the residue from bathing water, the result of washing baths. Water drainage system from household waste is by flowing from a higher place to a lower. Therefore, the household's height must be in an elevated position to drain the wastewater.

After completing the construction of the wastewater management installation, data is needed to see the effect that this development has had on global warming and several other existing impacts. Life cycle assessment is used in the form of an LCA stage and sees the effect, which has four steps in the process and scope be carried out. This scope is in the form of a system limitation to be observed. First, this study determines the purpose, namely, to see the environmental impact resulting from the manufacture of wastewater management from households. Then the limit is from the beginning, starting from the entry of wastewater from families to the results of wastewater management that can be reused.

The LCA process used in the wastewater treatment plant will carry out the LCA method steps [3]. The stages of these stages are Goal and Scope, Inventory, Impact Analysis and Interpretation. The four phases must be carried out correctly to provide good results when making decisions for improvements in each process unit carried out. When carrying out goals and scope, the process determines the goals to be achieved in wastewater management. In this research, the purpose will be defined, namely, to obtain wastewater management from the population and, in the end, will get the water conditions that can be reused. For water reuse managed, a functional unit will also be determined, which is 1 m^3 of water reuse [4].

Furthermore, inventory data that has been collected is following the number of resources used when managing. These resources include the number of electricity users, the number of water pump uses (kWh). After carrying out the inventory data, the LCA method's use will analyze the impacts that occur.

The impact that can arise from the use of wastewater an analysis will be made of the three impacts of the resulting implications for human health, the environment, and resources. First, for eco-efficiency, it is intended in this study to reduce the environmental impact of the unit. The concept of eco-efficiency is to improve the quality of life of a product and then reduce the magnitude of the effect on the environment and resources through the life cycle; therefore, it can produce the final product obtained and be reused [11].

The methodological framework used on the life cycle provided by the international standards organization (ISO) 14040 assesses the

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environmental impact of on-site wastewater treatment processes [3,2]. The impact assessment carried out with a simple LCA is to visualize and analyze the wastewater treatment process's environmental impact. Modelling materials and energy flows were carried out using the Eco-invent data collection software [12]. The openlcaecoinvent software can also give good results after inputting the input values into the LCA process. The data obtained from the research location will be input data, or it can also be said as primary data. If the data obtained cannot be obtained directly from the background, secondary data can also be obtained from secondary information. The use of secondary data also does not reduce the analysis to be carried out. However, the data we receive secondary to it must also be displayed transparently, and there is no uncertainty in determining the unit of function to be performed. For further analysis, it can also be used to use simapro software to see other impacts generated from each process carried out. Apart from the global impact that occurs, it can also produce other consequences such as ODP (Ozone Depletion Potential), POCP, Ecotoxicity and Acidification.

To perform this analysis is a life cycle assessment (LCA) based on a complete understanding of the amount of data realistically obtained. Life Cycle Assessment (LCA) is a compilation and evaluation of outputs and potential environmental impacts throughout its life cycle. The LCA study helps in determining the best method/technique from an ecological point of view. For LCA, four stages are required for the LCA study: definition of objectives and scope, analysis of life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation [12]. The LCA water treatment system finds importance in recent literature because of its holistic approach. Several studies have also been conducted on LCA, which has a problem with wastewater. One of the most recent studies comparing various wastewater treatment techniques is a combination of aerobic to anaerobic, chemical to chemical and biological [13]. It was recycling phosphorus for cropland (because of its potential for fertilization) [14] better controlled to reduce the impact of fossil fuel depletion and climate change than sludge incineration [15,16].

Material and Methods

This research was conducted on the use of raw materials used in the management process. This research was conducted only in the gate to gate process. The following are the stages of the study:

Data collection

The data is obtained in two ways: making direct observations on the waste management process and conducting interviews with landowners to construct installations and receive data to conduct a study. Primary data is data that comes directly from the landowners for putting into inventory without experiencing data processing. Data can be obtained from the interviewers in the form of input and output of the wastewater plant. When collecting data, we must provide the amount or unit that will be used. The sources used from nature must be explained whether the source comes from the processing's heart. If the start of the raw material used comes from nature, it will be presented in the unit process that will be carried out.

Data processing

Data processing can be done by using the Life Cycle Assessment (LCA) method with the help of software, namely using the SimaPro 9.1.0.8 Educational software, then measuring the Eco-Efficiency Index (EEI) and the Eco-Efficiency Ratio (EER Rate) [17]. Therefore, the data processed in the study can use the Eco-Efficiency Index (EEI) method.

The Eco-Efficiency Index is a calculation or index to determine whether a product can be affordable (financially affordable) and sustainable (environmentally friendly). EEI calculations can be done with the formula, as shown in Table 1. The eco-efficiency calculations result by explaining the state or status, namely if the EEI > 1, then the condition is financially acceptable, and the environmental conditions can also be sustainable. If EEI = 0 - 1, then the financial situation will also be sufficient, but the resulting environmental conditions are not sustainable. If the EEI <0, it is not acceptable financially and cannot provide a sustainable ecological condition. Eco-Efficiency Ratio (EER Rate).

No.	Process	Status	
1	Eco-Efficiency > 1	affordable	sustainable
2	Eco-Efficiency = 0 - 1	affordable	not sustainable
3	Eco-Efficiency < 0	non - affordable	not sustainable

Table 1: Criteria for Eco-Efficiency Index.

The EER Rate value is part of the calculation to determine the eco-efficiency level, calculated by looking for the Eco Cost Value Ratio (EVR) first [17]. Then by doing the EER Rate method by determining the eco cost-value ratio by dividing the eco cost by the net value.

Life cycle assessment (LCA)

Life Cycle Assessment is a quantitative method used and then assesses or measures the impact humans have on the environment. LCA's benefit is to provide information on the effects caused by processes, products, operations and measurements on the ground. The Life Cycle Assessment using SimaPro 9.1.0.8 Educational software and the Damage Assessment value is obtained from the Life Cycle Assessment calculation. There are three groups, namely Human Health with DALY (Disability Adjusted Life Year) units, Environmental Ecosystems (ecosystems quality) in PDF * m2yr units (Potentially Disappeared Fraction of Species per Square Meter per Year), a resource with surplus MJ units. Furthermore, the LCA results then determine the eco cost value converted into rupiah using the formula in the table below [18,8] and convert the currency value from euros to rupiah as presented in Table 2.

No.	Unit	Conversion	The value of the currency
1	PDF m^2yr	1.4	Euro
2	MJ Surplus	0.00411	Euro
3	DALYs	74000	Euro
4	1 Euro	17,114.70	Rupiah

Table 2: Unit Conversion to Currency Value.

Table 2 above describes the conversion from PDF m^2yr to financial value (euros), which is 1.4 euros. Furthermore, MJ Surplus is worth 0.00411 euros, and DALYs is worth 74,000 euros. Therefore, to see the value in rupiah, the value of 1 euro is IDR 17,114.70.

Eco-Efficiency index (EEI)

$$EEI = \frac{Price - Cost}{Eco\ Cost}$$

The Eco-Efficiency Index is a calculation or index to determine whether a product can be affordable (financially affordable) and sustainable (environmentally friendly). EEI calculations can be done with the formula, as shown in the equation. Data were obtained from both primary and secondary sources. Preliminary data were obtained with structured questionnaires and interview schedules from literate and illiterate farmers in the study area. In contrast, secondary data were obtained from annual reports of the state Agricultural Development Programme, textbooks, journals, the internet and previous studies of other researchers.

Eco-Efficiency ratio (EER Rate)

The EER Rate value is part of the calculation to determine the eco-efficiency level, calculated by looking for the Eco Cost Value Ratio (EVR) first [17].

$$EVR = \frac{Eco\ Cost}{Net\ Value}$$

$$EER\ Rate = (1 - EVR) \times 100\%$$

Results and Discussion

Environmental impact calculations

The calculation of environmental impact estimates the impact of the raw materials used in the wastewater management process. Environmental impact calculations are carried out using SimaPro software. The nine types defined by the abbreviation are climate change or global warming potential (GWP). The others are freshwater eco-toxicity potential (FETP), freshwater eutrophication potential (FEP), human toxicity potential (HTP), metal depletion potential (MDP),

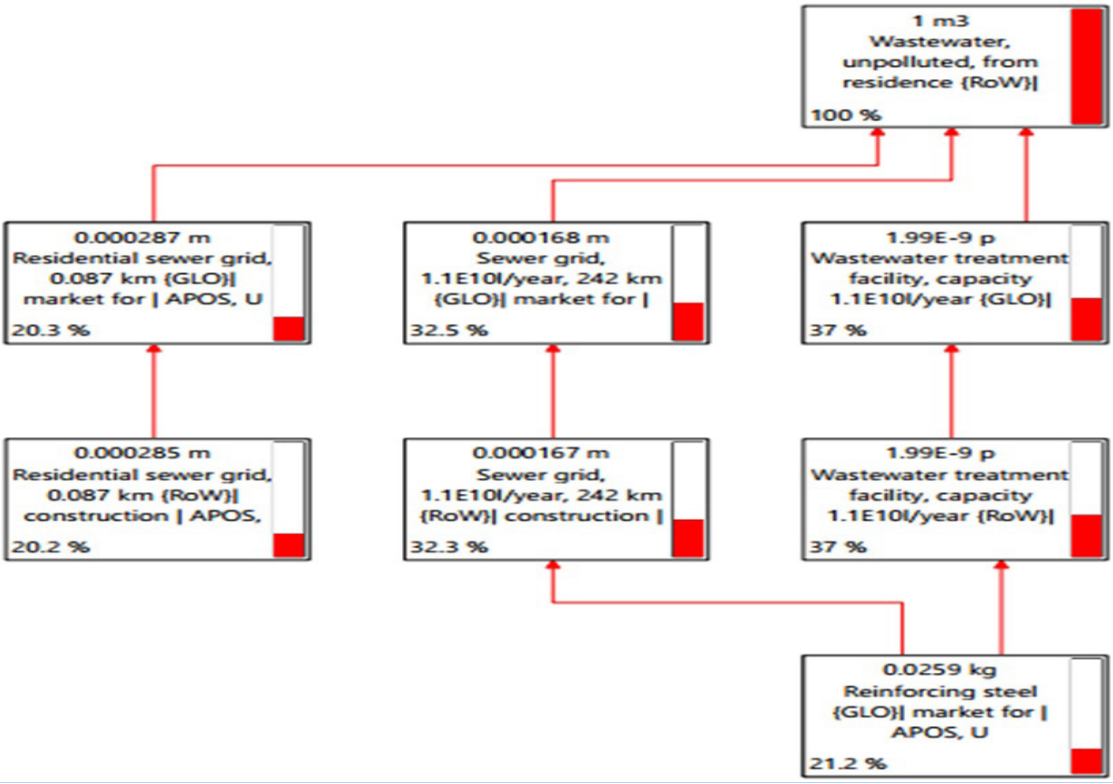

Figure 1: Networking the normalization of the human health.

Impact Category	Unit	Installation	Information
Carcinogens	DALY	1.46×10^{-8}	The Daly Unit has the greatest value in the Resp category. Inorganics (DALY), which is 2.57 x 10-7 and for land use (PDF m2yr), gives the largest value of 0.0768 and the smallest is acidification/ eutrophication is 0.00622.
Resp. organics	DALY	2.94×10^{-10}	
Resp. inorganics	DALY	2.57×10^{-7}	
Climate change	DALY	6.71×10^{-8}	
Radiation	DALY	1.92×10^{-11}	
Ozone Layer	DALY	1.87×10^{-11}	
Ecotoxicity	PDF m^2yr	0.00441	
Acidification/ Eutrophication	PDF m^2yr	0.00622	
Land Use	PDF m^2yr	0.0768	
Minerals	MJ Surplus	0.0338	

Table 3: Analisis Impact Category.

depletion ozone potential (ODP), particulate matter formation (PMF), terrestrial eco-toxicity potential (TETP), and water depletion potential (WDP). That can be seen in Figure 1, Table 3, Figure 2, Table 4.

Human health (human health) in the table is 0.00339 DALY, which means 0.00339 years of healthy life lost for a person. The quality of the ecosystem (Ecosystem Quality) produced is 874,123 PDF * m^2yr, which means damage to species or ecosystems covering an area of 874,123 m^2 in one year. Resources (resources amounting to 5.8234 MJ surplus) indicates the amount of raw energy needed to extract a natural resource is 5.8234 MJ surplus (Table 5).

Damage Category	Unit	WWTP
Human Health	DALY	0.00339
Ecosystem Quality	PDF m^2yr	874.123
Resources	MJ Surplus	5.8234

Table 5: Total Damage Assessment Proses.

Eco cost calculation

Eco cost must be spent to overcome the environmental impact caused by the product life cycle process (Table 6).

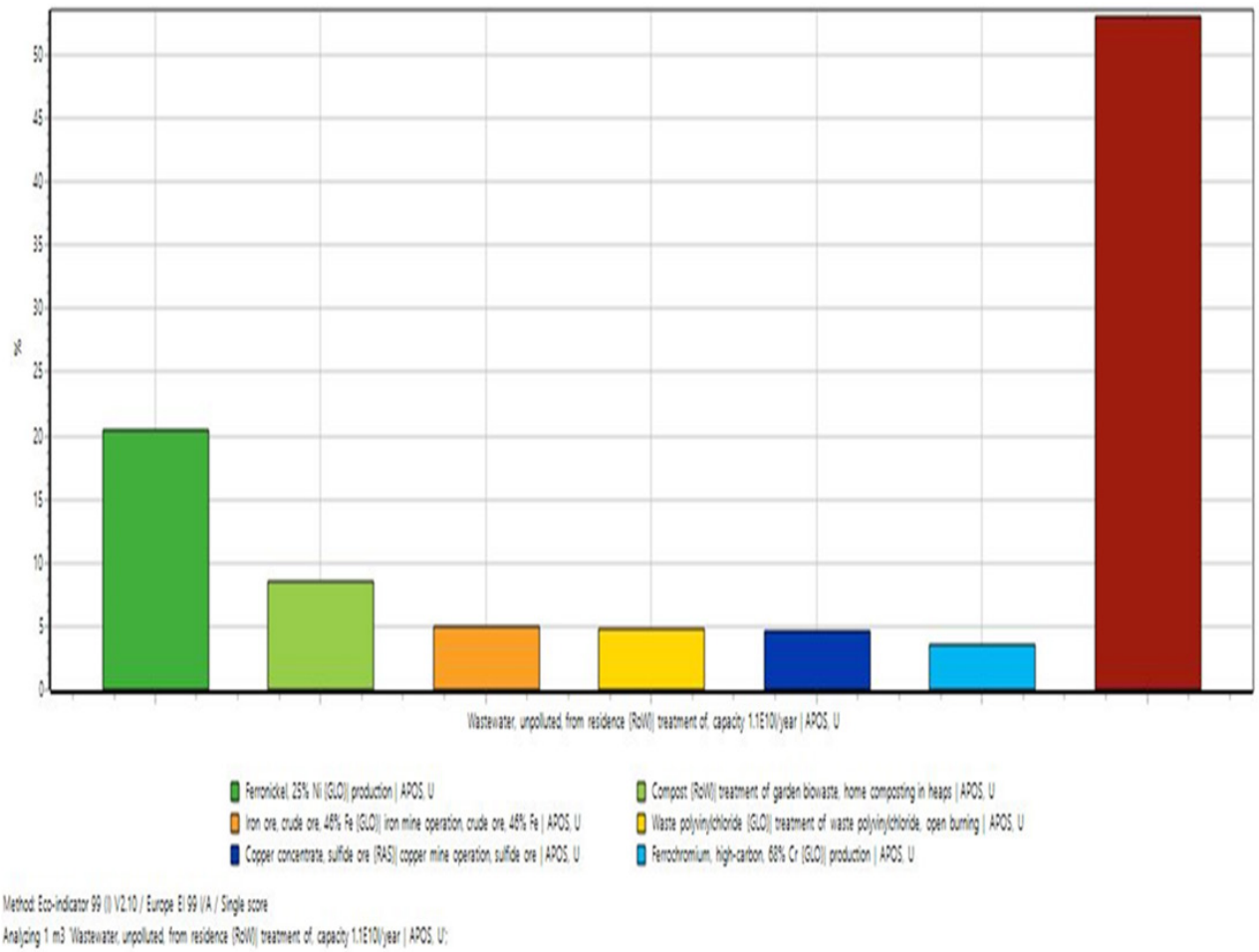

Figure 2: Process Contribution damage emissions.

No	Process	Project	Unit	Wastewater unpolluted
	Total of all process		%	100
	Remaining process		%	53
1	Ferronickel, 25% Ni{GLO}|production|APOS, U	Ecoinvent 3 – allocation at	%	20.5
2	Compost {RoW} treatment of garden biowaste, home composting in	Ecoinvent 3 – allocation at	%	8.53
3	Iron ore, crude ore, 46% Fe {GLO} iron mine operation, crude ore, 46°	Ecoinvent 3 – allocation at	%	5.04
4	Waste polyvinylchloride {GLO} treatment of waste polyvinylchloride	Ecoinvent 3 – allocation at	%	4.74
5	Copper concentrate, sulfide ore {RAS} copper mine operation, sulfide	Ecoinvent 3 – allocation at	%	4.68
6	Ferrochromium, high-carbon, 68% Cr{GLO}|production| APOS, U	Ecoinvent 3 – allocation at	%	3.51

Table 4: Table of Process Contribution damage emission.

Damage Category	Unit	WWTP	Total Eco Cost
Human Health	DALY	0.00339	IDR 4,293,393.642
Ecosystem Quality	PDF m^2yr	874.123	IDR 20,944,494.071
Resources	MJ Surplus	5.8234	IDR 409,629

Table 6: Eco Cost WWTP.

From the Eco Cost calculation, the results obtained for the eco cost for Human Health are IDR 4,293,393.642 Ecosystem Quality are IDR 20,944,494.071, and Resources are IDR 409,629.

Calculation of Eco-efficiency index (EEI) and Eco Cost value ratio (EVR)

The Eco-Efficiency Index (EEI) is a division between net value and eco cost. Meanwhile, the Eco Cost Value Ratio (EVR) is the opposite of EEI, namely the division between eco cost and net worth [18-20]. The Eco-Efficiency Ratio (EER Rate) results from the EVR multiplied by 100% to get the percentage level of eco-efficiency, as shown in Table 7.

Type of Cost/ Year	Amount
Net Value	IDR 4,565,879,242
Eco Cost	IDR 25,647,516.712

Table 7: Net Value Product Installation.

The value of the Eco-Efficiency Index (EEI) in the wastewater management installation is 0.183. Thus the building can be affordable (financially affordable) and not sustainable (not environmentally friendly) because the eco cost value is greater than the net worth of the WWTP. Meanwhile, the Eco-Efficiency Ratio (EER Rate) = (1-EVR) multiply by 100% and the value in the installation is -445.81%, as shown in Table 8.

Value	Unit	Percentage
Eco-Efficiency Index (EEI)	Index	0.178
EVR	Index	5.458
EER Rate	%	-445.81

Table 8: Calculation of the value of the Eco-Efficiency Index and the Eco-Efficiency Ratio.

Conclusions

The total damage assessment resulting from the process is human health (DALY) of 0.00339, ecosystem quality (PDF m^2yr) of 874,123 and resources (MJ Surplus) of 5,8234. Then the eco cost value for human health is IDR 4,293,393.642, and ecosystem quality is IDR 20,944,494.071, and resources are IDR 409,629. Therefore, the costs that must be spent to restore the restoration of environmental conditions caused by the wastewater treatment plant process using the life cycle method have the most prices for fixing the ecosystem quality, followed by human health conditions. The last one is resources. Then the Eco-Efficiency Index (EEI) value in the wastewater management installation is 0.178. Thus the building can be affordable (financially affordable) and not sustainable (not environmentally friendly) because the eco cost value is greater than the net value of the WWTP.

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Competing Interests

The author declare that there is no competing interests regarding the publication of this article.

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