Poll Res. 39 (2) : 232-239 (2020)

ISSN 0257–8050

WASTEWATER TREATMENT PLANT LIFE CYCLE ASSESSMENT: A CASE STUDY IN BATU CITY AND KEPUTIH WASTEWATER TREATMENT PLANT

NIEKE KARNANINGROEM[1] AND MAS AGUS MARDYANTO[2]

Department of Environmental Engineering,
Institut Teknologi Sepuluh Nopember, Sukolilo 60111, Indonesia

(Received 26 November, 2019; accepted 15 January, 2020)

ABSTRACT

The contribution of environmental impacts due to the treatment process of Kota Batu IPLT sludge treatment with a life cycle assessment (LCA) approach is that Aquatic acidification has an impact of 0.28 times, Non Renewable Energy has an impact of 0.25 times, and Global Warming has an impact of 0.27 times when compared to the Keputih IPLT. The difference in impact from the processing of sewage sludge produced by each IPLT is influenced by the resilience of the treatment unit to the burden of wastewater, the number of people that can be served, investment costs (construction, operation and maintenance), land requirements, ease of operation and maintenance, energy requirements, sludge generated, as well as disturbances and profits generated in addition to the previous aspects.

KEY WORDS : Environmental impact, Faecal sludge, Batu WWTP, Keputih WWTP, Life Cycle Assessment (LCA).

INTRODUCTION

With the passage of time, from urban growth to infectious disease and newly identified contaminations in water, greater demands are being placed on water supply (and other natural resources) (Spellman, 2014). Wastewater treatment system has been designed to control water pollution and protect clean water supply continuity. The treatment involves breakdown, either physicochemically or by using microorganisms (biological treatment), of complex organic compounds in the wastewater into simpler compounds that are stable and nuisance free (Sivasubramanian, 2016). However, in its operation, it consumes energy and chemical reagents, while produce sludge and various emissions that can cause environmental damage (Wu *et al.*, 2010). The different configurations regarding the wastewater treatment processes affect the environmental performance of a wastewater treatment plant (Al-Dosary *et al.*, 2015).

LCA is a standardized tool to evaluate various potential environmental impacts of a system product throughout its life cycle. It is comprised of goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and results interpretation (ISO, 2006). The analysis deals with three areas of scientific knowledge and reasoning named as "spheres" (Raghuvanshi *et al.*, 2017), they are technosphere (the explanation of the life cycle and the emission from processes), ecosphere (the modeling of changes inflicted on the environment), valuesphere (the modeling of the perceived seriousness of such changes). The use of LCA is particularly suited to wastewater treatment plant analysis due to the nature of the relationship between a plant's technosphere and the surrounding ecosphere (McNamara *et al.*, 2016).

Batu City IPLT uses SSC (Solid Separation Chamber) and ABR (Anaerob Baffled Reactor) units with the principle of biological waste treatment. While Keputih IPLT uses activated sludge technology with the unit used is oxidation ditch -

clarifier equipped with polishing pond.

This study assessed Batu WWTP and the result compared with assessment result of Keputih WWTP. The result would be a reference for other wastewater treatment plant and future projects to manage the possible environmental impacts according to the treatment process and geographical condition.

MATERIALS AND METHODS

Goal and scope

The goal of this LCA study is to assess the environmental benefits and drawbacks of a municipal wastewater treatment plant (in Batu, Indonesia) in comparison with other wastewater treatment plant with advanced treatment process (in Surabaya, Indonesia). The Batu WWTP was operated since 2016 and does not have any improvement since then. The average influent flow measured was approximately 36 m^3/day. This plant features anaerobic baffled reactor, facultative pond and maturation pond. There is no water pump or chemical reagent needed in this process. It depends solely on the biological process in each pond. However, the detention time was quite long. It took minimum 29 days for wastewater to be safely discharged.

The LCA study of the Batu WWTP was carried from a "gate-to-gate" perspective. It covers the process associated to treated wastewater, including the operation and maintenance (O&M) phase, transportation and sludge treatment. The construction and demolishment phase of the treatment plant was excluded due to insufficient data. Fig. 1 shows the flow diagram of the system.

The Surabaya WWTP was built in 1989 to 1990 and started to be operated in 1991. It had been through a lot of renovation every year. The treatment capacity of Surabaya WWTP is 100-150 m^3/day, however the current influent flow measurement still on 73,68 m^3/day. This case represents advanced technology with oxidation ditch, final clarifier, and polishing pond.

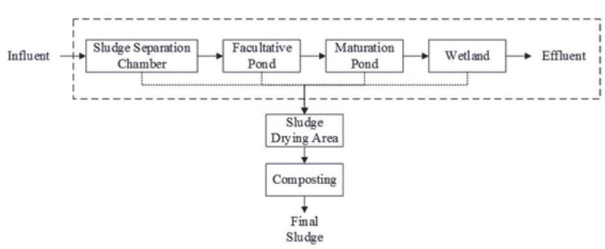

Fig. 1. Treatment Process Network in Batu City WWTP

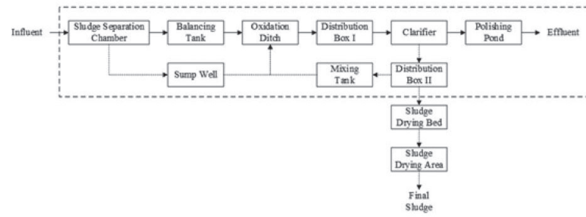

Fig. 2. Treatment Process Network in Keputih WWTP

Life cycle inventory

In this step, the natural resource, energy consumption, and emission of evaluated system is inventoried. Simapro 8.5 already has the basic database that can support the study, yet sufficient data is still needed. This process requires accurate and comprehensive data from reliable resources. It would consume a lot of time to gather the whole qualified and representative data because it is determined the final result (Boggia *et al.,* 2009).

Life cycle impact analysis

Significant potential environmental impacts of processes / products based on LCI are evaluated using impact assessment. This phase aims to classify and assess significant environmental impacts. In the process of estimating environmental impacts, the method used will be selected according to the research conducted. Several stages in determining the value of environmental impacts are generated into numbers.

- Characterization
- Normalization
- Weighting
- Single score

Interpretation Data

The final stage of the LCA method is to interpret data. The results of the previous three stages, then final conclusions are taken. The combination of results from life cycle inventory and life cycle impact assessment is used to interpret, draw conclusions and recommendations that are consistent with the goals and scope identified previously (EPA, 2006). After learning all the impacts that have been generated on a series of processes, one process was chosen that had the greatest impact on LCA.

RESULT AND DISCUSSION

Primary and Secondary Data Collection

Primary data collection was carried out by laboratory analysis as a result of sampling the quality of sludge effluent, questionnaires and interviews with informants who understood processing activities. Sampling was started in Mei-Agust 2019 which was guided by SNI 6989.59: 2008, namely if the industry already had WWTP taken at the location before and after WWTP taking into account the detention time (td). Detention time is obtained from design criteria. The value of detention time can be seen in Table 1.

From the results of laboratory analysis, it will be known the effluent value of each processing unit inlet and outlet. From here it can be done calculating the incoming mass load at each processing unit with the discharge that has been obtained from secondary data. The results of laboratory analysis of sewage effluent can be seen in Table 2.

Table 1. Detention time in Batu City WWTP

Unit	Waktu Detensi	Satuan
Solid Separation Chamber	5 – 12	Hari
Anaerobic Baffled Reactor	6 – 20	Jam
Kolam Fakultatif I	4 – 5	Hari
Kolam Fakultatif II	4 – 5	Hari
Kolam Maturasi I	5 – 15	Hari
Kolam Maturasi II	5 – 15	Hari

Source: Lampiran II Permen PUPR No. 4 Tahun, 2017

Secondary data collection was obtained from the Batu City WWTP and Keputih WWTP covering processing debits used in the treatment process of sludge. Feces that enter the WWTP will be treated aerobic and anaerobic. In addition to data from the WWTP, secondary data was obtained from literature studies related to research.

Mass Balance

From the concentration value, mass load calculations can be carried out on each processing unit. Processing that can be seen in Fig. 3 and Fig 4. Following is the calculation of mass processing load for each unit:

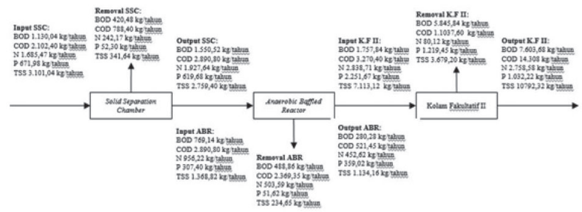

Fig. 3. Mass Balance in Batu City WWTP (a)

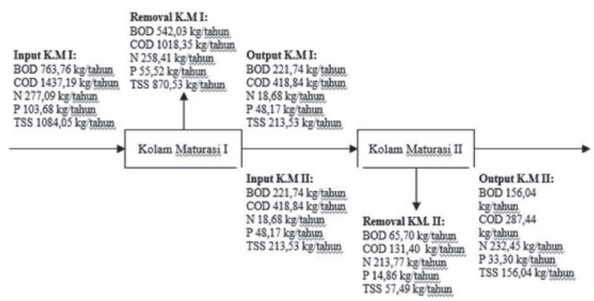

Fig. 3. Mass Balance in Batu City WWTP (b)

Tabel 2. Results of Analysis of Fecal Sludge in the Laboratory (a)

	Unit	Solid separation Chamber		Anaerobic Baffled Reactors		Fakultatif Pond II	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
pH	-	7.2	7.7	7.7	7.6	7.6	8.2
TSS	mg/L	236	210	210	174	174	264
N	mg/L	128.27	146.7	146.7	69.44	69.44	67.48
P	mg/L	51.14	47.16	47.16	55.08	55.08	25.25
COD	mg/L	160	220	220	80	80	350
BOD	mg/L	86	118	118	43	43	186

Table 2. Results of Analysis of Fecal Sludge in the Laboratory (b)

pH	Unit	Inlet	Outlet	Inlet	Outlet
pH	-	8.2	8.6	8.6	10
TSS	mg/L	264	52	52	52
N	mg/L	67.48	4.55	4.55	56.61
P	mg/L	25.25	11.73	11.73	8.11
COD	mg/L	350	102	102	70
BOD	mg/L	186	54	54	38

Goal and Scope Life Cycle Assessment

Processing with SimaPro 8.5.2 Software The first step is to determine the definition of the objectives and scope of the research. This stage helps the consistency of LCA research. The purpose of this study was to analyze the contribution of environmental impacts due to the treatment process of sludge in the Batu City using the life cycle assessment (LCA) method. The reasons for carrying out the research must be clearly explained. Research limits determine which process units are included in the LCA study. The following stages of goal setting can be seen in Fig. 5.

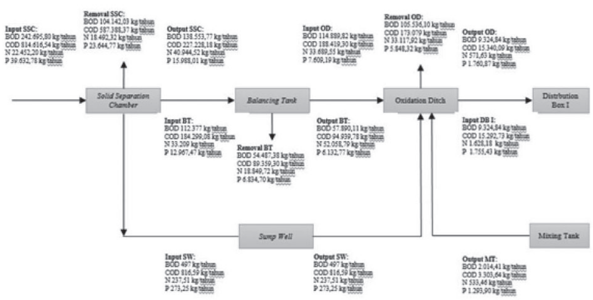

Fig. 4. Mass Balance in Keputih WWTP (a)

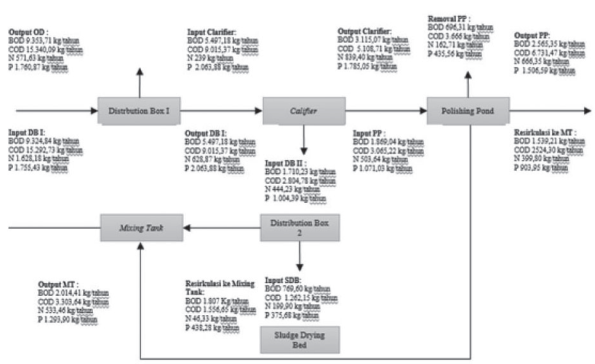

Fig. 4. Mass Balance in Keputih WWTP (b)

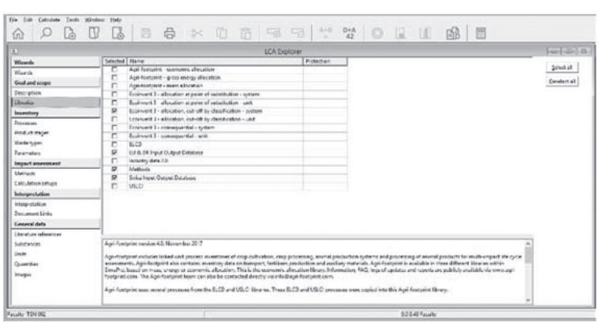

Fig. 5. Goal and Scope

Next, determine the scope or boundaries of the study to be examined in Figure 6 At this stage the scope of the research chosen is the ecoinvent database.

Input

Data input consists of two, namely foreground data, which refers to specific data to model the system by describing certain production systems. Background data is data for the production of generic materials, energy, transportation and waste management. This data can be found in the SimaPro database and from the literature. In the processing of sludge in each installation unit, the organic and inorganic mass loads are processed from the calculation of the discharge and concentration of each processing unit.

Output

The output in question is environmental impact. The impacts chosen in this study were aquatic eutrophication, global warming and non renewable energy from 14 categories of impacts caused by the treatment of sludge. The stage of determining scope can be seen in Figure 6.

Life Cycle Inventory

Life Cycle Assessment Processing with SimaPro 8.5.2 Software. At this stage inputting data, such as processing load on processing units during the process. Secondary data used specifically obtained from the Batu City WWTP included processing debits and process processing loads at the processing unit. Primary data obtained from the results of sampling and processing load calculations. Data is entered in the amount per year and is considered data per days in one year is constant. The results of this stage will later be described in a flow sheet or process tree. After data collection, an identification process with a goal and scope is carried out and calculates the inventory life cycle (LCI). The results of this network processing provide

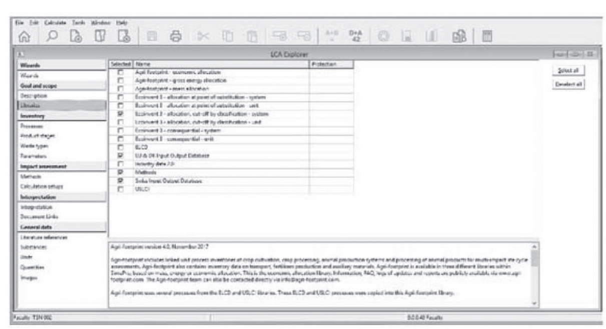

Fig. 6. Scope LCA

relationship information from each process that has an influence on impact contributions. The network for the entire treatment process of sludge can be seen in Figure 6. The black line is an environmental burden that occurs in all processing processes that contribute to the impact on the environment.

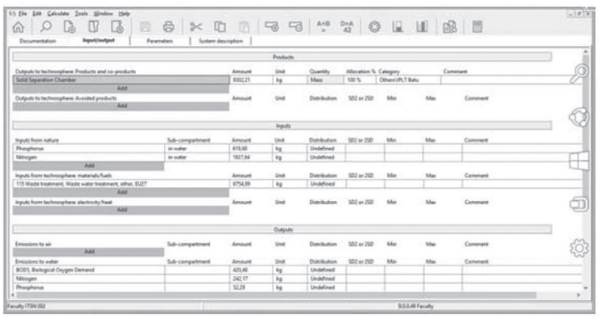

Fig. 7. Input LCA

Life Cycle Impact

Assessment Life Cycle Assessment Processing with SimaPro 8.5.2 Software. In the impact assessment phase, it is determined the impact on the environment that has been obtained from the Life cycle inventory (LCI) stage. The method in the SimaPro software used to estimate the magnitude of the impact that occurred was Impact 2002+. The Impact 2002+ method was chosen because it is the latest method and is a combination of the four previous methods, namely IMPACT 2002 (Pennington *et al.*, 2005), Eco-indicator 99 (Goedkoop and Spriensma, 2002, 2nd version, Egalitarian Factors), CML (Guinee *et al.*, 2002) and IPCC. The impact assessment carried out by SimaPro software is to directly compare the results of life cycle inventory (LCI) in each category. In the Impact 2002+ method, 14 impact categories will be produced, but will focus on three impacts, namely aquatic eutrophication, global warming, and non renewable energy.

Characterization

Characterization is the stage carried out by multiplying the substance of the impact category by characterization factors. Characterization factors are often called equality factors. The characterization value can be seen in Figure 8 showing a diagram of the impact of the sludge treatment process of IPLT Kota Batu. The results are in the form of a percentage. The method used in this study is the Impact 2002+ method. The Impact 2002+ method is a new method that connects all types of inventory life cycles through 14 midpoint categories (Impact 2002+ A New Life Impact Assessment Methodology, 2003).

The results shown are a percentage. The solid separation chamber unit produces 8.7% Aquatic acidification, 77.8% global warming and 77.8% non renewable energy. The anaerobic baffled reactor unit produces 9.3% Aquatic acidification, 6.2% global warming, and 6.2% non-renewable energy. The facultative pool unit 2 produces 51.5% Aquatic acidification, 12.8% global warming, 12.8% non renewable energy. Maturation pool 1 units produce 17.2% Aquatic acidification, 2% global warming, and 2% non renewable energy. Maturation pool 2 units produce 13.3% Aquatic acidification, 1.2% global warming and 1.2% non renewable energy.

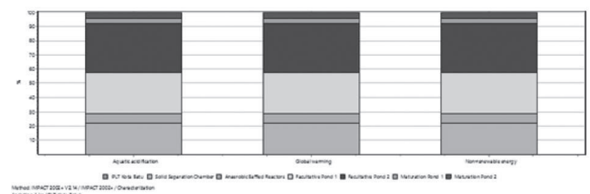

Fig. 8. Characterization Diagram

In Keputih WWTP, unit solid separation chamber menghasilkan 37,729% aquatic acidification, 59,227% global warming and 59,179% non renewable energy. Unit balancing tank menghasilkan 24,547% aquatic acidification, 21,423% global warming, and 21,414% non renewable energy. Unit sump well menghasilkan 0,117% aquatic acidification, 0,190% global warming, and 0,196% non renewable energy. Unit oxidation ditch menghasilkan 28,037% aquatic acidification, 15,867% global warming, 15,875% non renewable energy. Unit distribution box I menghasilkan 3,007% aquatic acidification, 1,423% global warming, and 1,424% non renewable energy. Unit clarifier menghasilkan 1,878% aquatic acidification, 0,681% global warming and 0,685% non renewable energy. Unit distribution box II menghasilkan 1,097% aquatic acidification, 0,303% global warming and 0,308% non renewable energy. Unit polishing pond 1,867% aquatic acidification, 0,429% global warming and 0,434% non renewable energy. Unit mixing tank 1,331% aquatic acidification, 0,328% global warming and 0,333% non renewable energy. Unit sludge drying bed 0,391% aquatic acidification, 0,129% global warming dan 0.152% non renewable energy. The

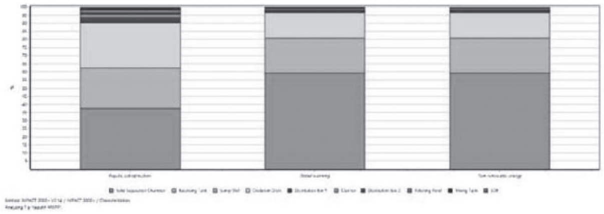

Fig. 9. Characterization Diagram in Keputih WWTP

Table 4. Damage Factors Characterization

Midpoint Category	Demage Factors	Unit
Aquatic acidification	8.82 × 10^{-3}	PDF-m^2.y
Global warming	1	kg CO_2/tahun
Non renewable energy	45.6	MJ

Source : IMPACT 2002+

characterization value can be seen in Figure 9. showing a diagram of the impact of the sludge treatment process of Keputih WWTP.

The characterization factor of damage to the substance can be obtained by multiplying the potential of the existing midpoint characterization with the factor of characterization of damage to the substance. Table 4 shows the characterization factors for various substances.

The results of the impact assessment of the whole process based on characterization and characterization values can be seen in Table 5 and 6.

Normalization

This stage of normalization is carried out to facilitate comparison between impact categories. The normalization factor in Table 7 is determined by the impact ratio per unit divided by the total impact of all substances from a particular category for which characterization factors exist, per person per year. Value impact category from characterization divided by normal values so that all impact categories use the same unit or unit so that the value can be compared.

In Figure 10 and 11 the results of the normalization diagram that are seen only the effects of aquatic eutrophicion, global warming and non renewable energy. The results of normalization in the treatment process of sludge can be seen in Table 8 and 9.

Table 5. Characterization Value in Batu City WWTP

Unit	Midpoint Category		
	Aquatic acidification (PDF-m^2.y)	Global warming (kg CO_2/tahun)	Non renewable energy (MJ)
SSC	0,000029	1,19	330,56
ABR	0,000011	0,21	19,60
Kolam Fakultatif II	0,000001	0,05	15,09
Kolam Maturasi I	0,000008	0,31	84,96
Kolam Maturasi II	0,000005	0,19	51,64
Total	0,00005	1,94	501,86

Table 6. Characterization Value in Keputih WWTP

Unit	Midpoint Category		
	Aquatic acidification (PDF-m^2.yr)	Global warming (kg CO_2 eq)	Non renewable energy (MJ)
SSC	0,000025	1,01	281,20
Balancing Tank	0,000018	0,73	203,84
Sump Well	0,001524	61,96	17.253,60
Oxidation Dicth	0,000104	4,24	1.179,84
Distribution Box I	0,000015	0,59	165,72
Clarifier	0,000011	0,45	126,75
Distribution Box II	0,000004	0,16	44,44
Polishing Pond	0,000009	0,35	97,49
Mixing Tank	0,000008	0,33	93,55
Sludge Drying Bed	0,000010	0,36	117,07
Total	0,001727	70,18	19.563,50

Comparison of the results of the Batu City WWTP LCA and the Keputih WWTP

The impact of environmental pollution generated in the processing of sludge sludge treatment of Batu City WWTP using the life cycle assessment (LCA) method is global warming by releasing CO2 emissions of 1.94 kg CO2 / year, non-renewable energy by issuing energy emissions of 501.86 MJ, and aquatic acidification which can lead to the potential loss of aquatic species with an emission value of 0.00005 PDF.m2. Research that previously contributed to the environmental impact due to IPLT Keputih sludge treatment process with a life cycle assessment (LCA) approach was global warming of 70.18 kg CO_2/year, non-renewable energy of

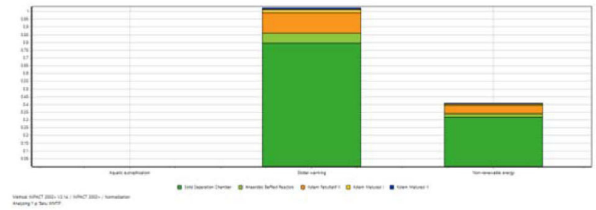

Fig. 10. Normalization Diagram in Batu City WWTP

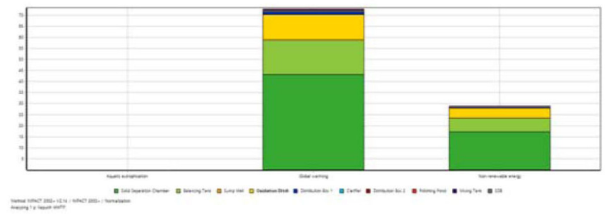

Fig. 11. Normalization Diagram in Keputih WWTP

Table 7. Normalization Factors

Damage Categories	Normalization Factors	Unit
Human Health	0,0077	DALY/pers/yr
Ecosystem Quality	4650	PDF-m2.yr/pers/yr
Climate Change	9950	kg CO2/pers/yr
Resources	152000	MJ/pers/yr

Table 8. Normalization Value in Batu City WWTP

Unit	Impact Category		
	Aquatic acidification (PDF-m^2.y)	Global warming (kg CO_2/tahun)	Non renewable energy (MJ)
SSC	0	0,000081	0,0000021
ABR	0	0,0000064	0,0000002
Kolam Fakultatif II	0	0,0000131	0,0000003
Kolam Maturasi I	0	0,0000020	0,0000001
Kolam Maturasi II	0	0,0000013	0,00000003
Total	0	0,000103	0,0000027

Table 9. Normalization Value in Keputih WWTP

Unit	Impact Category		
	Aquatic acidification (PDF-m^2.yr)	Global warming (kg CO_2/pers.yr)	Non renewable energy (MJ)
SSC	0	0,0043	0,00011
Balancing Tank	0	0,0016	0,000041
Sump Well	0	0,00013	0,0000004
Oxidation Dicth	0	0,0012	0,00003
Distribution Box I	0	0,00011	0,0000027
Clarifier	0	0,000049	0,0000013
Distribution Box II	0	0,000022	0,0000006
Polishing Pond	0	0,000031	0,0000008
Mixing Tank	0	0,0000240	0,0000006
Sludge Drying Bed	0	0,0000095	0,0000003
Total	0	0,0073	0,00019

Table 10. Comparison of Batu City WWTP and Keputih WWTP

Impact Category	Kota Batu WWTP	Keputih WWTP	Perbnadingan Dampak
Aquatic acidification (PDF-m^2.yr)	0.00005	0.001727	0.02895
Global warming (kg CO_2//pers.yr)	1.94	70.18	0.02764
Non renewable energy (MJ)	501.86	19.563,50	0.02565

19,563.50 MJ and aquatic eutrophication of 0.02895 PDF.m^2.y. Then compared with the two studies on the treatment process of Batu City WWTP sludge treatment with Keputih IPLT sludge treatment in Surabaya and can be seen in Table 10 and the comparison diagram can be seen in Figure 12.

Fig. 12. Comparative Impact Chart for WWTP

From Table 10 and Figure 12, it can be seen that the impact value of the Kota Batu WWTP sludge treatment process on the impact of Aquatic acidification has an impact of 0.28 times, Non Renewable Energy has an impact of 0.25 times, and Global Warming has an impact of 0.27 times when compared to the Keputih IPLT.

The difference in impact from the processing of sewage sludge produced by each IPLT is influenced by the resilience of the treatment unit to the burden of wastewater, the number of people that can be served, investment costs (construction, operation and maintenance), land requirements, ease of operation and maintenance, energy requirements, sludge generated, as well as disturbances and profits generated in addition to the previous aspects.

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