LIFE CYCLE ASSESSMENT OF DOMESTIC WASTEWATER TREATMENT IN MEDAN CITY, INDONESIA

Ira Rumiris Hutagalung[*,1], Toru Matsumoto[2]

[1)]Graduate School of Environmental Engineering, the University of Kitakyushu, Japan
[2)]Faculty of Environmental Engineering, the University of Kitakyushu, Japan

Abstract

Medan City already has been having Waste Water Treatment Plant (WWTP) under PDAM Tirtanadi (North Sumatera Government) supervision, namely IPAL Cemara. IPAL Cemara is off-site sewerage system to treat domestic wastewater, includes black and grey water. IPAL Cemara has maximum capacity 60,000 m^3/day, but recently, the number of treated households by IPAL Cemara is 18,396 households and the used capacity is less than 10,000 m^3/day. This research analyses on operational phase of IPAL Cemara on environmental impacts, starts at wastewater influent from households and ending at release of wastewater effluent and disposal of dry sludge. The phase of reuse or recycle of effluent wastewater and dry sludge, and waste management are not included. Functional unit in this research is treatment of 7,171 m^3 wastewater per day for a year. The system boundary starts at wastewater influent and ends at release of wastewater effluent. The characterization factors are tracked based on CML Baseline 2001 and all of data processed by Microsoft Excel. For the result, got that Aerated Pond has removal efficiency of BOD and COD more than 70%, but on the other hand, it is the largest contributor to Climate Change impact because of diesel consumption (16.97%), the amount of CO_2 (4,95%), and N_2O (4.26%) from biogenic emission, and electricity use (3.04%). The 65% reducing of TSS is occurred in UASB Reactor but UASB Reactor also as contributor for Climate Change impact (16.63%) and Photo-Oxidant Formation impact (29.34%) due to the highest production of CH_4. Facultative Pond contributes 49% of Climate Change impact and 31% of Photo-Oxidant Formation impact because of the highest production of CH_4. Based on normalized by impact category, Freshwater Ecotoxicity and Eutrophication is the largest environmental impact in a whole system of IPAL Cemara. Freshwater Ecotoxicity caused by 72% CS_2 at Release of Wastewater and Eutrophication caused by 41.25% of NH_3 and 39.60% of N. It is Align with the result of normalized by Life Cycle Stage, shows that the Release of Wastewater Effluent is the largest contributor to environment in a whole system of IPAL Cemara.

Keywords: *Life Cycle Assessment, Domestic Wastewater Treatment*

Introduction

Medan City where is the capital city of North Sumatera province is the 3rd biggest city in Indonesia with the large area is 265.10 km^2, consists of 2,210,624 inhabitants. The average density of Medan City is 8,338 person/ km^2 and the average household size is 4.35 people/ household. The population of Medan City always increases year by year and for along 15 recently years, the increasing reaches 16%.

The increasing of population will increase household consumption of water and directly

[*)]Corresponding Author:
E-mail: irarumirishutagalung@gmail.com

Received: 3 April 2020
Revised : 13 July 2020
Accepted: 12 September 2020

impacted to increase domestic wastewater production (Prinajati, 2020). As we have known that around 80% water consumption becomes wastewater (www.iges.or.jp, accessed March 2017). Domestic wastewater disposal without adequate treatment causes water sources contamination for drinking water, ground water, and river water (Yustiani et.al, 2018). Rapidly increasing of population leads some environmental issues in Medan City and the 2nd biggest issue is decreasing rivers quality (Book of Environmental Status of Medan City, 2015).

Since 1995, Medan City already has been having Waste Water Treatment Plant (WWTP) under PDAM Tirtanadi (North Sumatera Government) supervision, namely IPAL Cemara. IPAL Cemara is off-site sewerage system to treat domestic wastewater, includes black and grey water. IPAL Cemara covers some areas of Medan City and Deli Serdang Regency with total coverage areas are 520 Ha of Medan City and 150 Ha of Deli Serdang Regency. However, the coverage area is low, only 3.63% of domestic wastewater is treated by IPAL Cemara. Approximately, 96.37% of households in Medan City rely on on-site sewerage systems; those are septic tank or latrine pit for treating black water and open drainage for grey water.

Life Cycle Assessment (LCA) is technique for assessing the potential environmental aspects and potential aspects associated with a product or service, by: compiling an inventory of relevant inputs and outputs, evaluating the potential environmental impacts associated with those inputs and outputs, and interpreting results of the inventory and impact phases in relation to the objectives of the study (ISO 14040.2 Draft : Life Cycle Assessment-Principles and Guideliness (http://www.gdrc.org, accessed March 2017).

Recently, many LCA researches relate to domestic wastewater treatment, such as Application of LCA for an Evaluation of Wastewater Treatment and Reuse Project – Case Study of Xi'an, China (Zang et. Al, 2010), LCA of Wastewater Treatment Plants in Ireland (Mcnamara et.al, 2016), Comprehensive Life Cycle Inventories of Alternative Wastewater Treatment Systems (Foley et. Al, 2010), and LCA of a Municipal Wastewater Treatment Plant: A Case Study in Suzhou, China (Li et. al, 2013).

The objectives of this research are to find the operational impact of IPAL Cemara on environment by a whole system and each life cycle stage and to establish LCA framework of IPAL Cemara that could use as baseline to conduct continuous improvement and further deeply analysis.

Research Methodology

This research analyses on operational phase of IPAL Cemara on environmental impacts, starts at wastewater influent from households and ending at release of wastewater effluent and disposal of dry sludge. The phase of reuse or recycle of effluent wastewater and dry sludge, and waste management are not included.

a. Goal and Scope

This research aim at analyses on operational stage of IPAL Cemara on environmental impacts for establishing LCA framework that could be used to further research such as continuous improvement of IPAL Cemara. The research's scope includes wastewater influent, treatment and maintenance, treated water release, and disposed dry sludge. Functional unit in this research is treatment of 7,171 m^3 wastewater per day for a year. The system boundary starts at wastewater influent and ends at release of wastewater effluent. Electricity for operating machine and pump, diesel as generator fuel, lubricant consumption for operating and maintaining machine and pump are included within the system boundaries. Biogenic emissions, treated wastewater effluent, and disposed dry sludge are also included within the system boundaries. By-product production such as large solids, rags, debris, sand, gravel, cinder from Screening and Grit Chamber, also sludge from Aerated Pond and Facultative Pond are calculated but the environmental impacts of them are not take account. Based on interview with IPAL Cemara staff, the estimation of lubricant spill is 3% of lubricant residue, 97% is collected well and given to third party.

b. Life Cycle Inventory (LCI)

The LCI of this research is CML Baseline 2001 from Leiden University. Accordance with CML 2001 guidance, there are some required data of IPAL Cemara operational, such as electricity use of each pump and machine, diesel consumption as generator fuel of each and machine, the amount of CO_2, CH_4, and N_2O as air emission from electricity use, diesel and lubricant consumption, biogenic emissions, the constituents of treated wastewater effluent as water emission and disposed dry sludge as soil emission, and the number production of by-products. All of data in Life Cycle Inventory is collected based on the functional unit, which is treatment of 7,171 m^3 wastewater per day for a year.

Table 1. Data Sources

No	Life Cycle Stage	Unit Process/Process Emission	Required Data	Sources
1	Influent Box	Input and Output of Wastewater	Debit	Measured by Environmental Agency of North Sumatera Province
2	Screw Pump	Input and Output of Wastewater	Debit	Measured by Environmental Agency of North Sumatera Province
		Electricity	Quantity Used	Direct from IPAL Cemara
		Diesel and Lubricant Consumption	Quantity Used	Direct from IPAL Cemara
		CO_2, CH_4, N_2O (from electricity use, diesel consumption)	Quantity Generated	Estimation
3	Screening	Input and Output of Wastewater	Debit	Measured by Environmental Agency of North Sumatera Province
		Large Solids, Rags, Debris	Quantity Generated	Estimation
		Electricity	Quantity Used	Direct from IPAL Cemara
		Diesel and Lubricant Consumption	Quantity Used	Direct from IPAL Cemara
		CO_2, CH_4, N_2O (from electricity use, diesel consumption)	Quantity Generated	Estimation
4	Grit Chamber	Input and Output of Wastewater	Debit	Measured by Environmental Agency of North Sumatera Province
		Sand, Gravel, Cinder, and Other Heavy Solids	Quantity Generated	Estimation
		Electricity	Quantity Used	Direct from IPAL Cemara
		Diesel and Lubricant Consumption	Quantity Used	Direct from IPAL Cemara
		CO_2, CH_4, N_2O (from electricity use, diesel consumption)	Quantity Generated	Estimation
5	Splitter Box	Input and Output of Wastewater	Debit	Measured by Environmental Agency of North Sumatera Province
6	UASB Reactor	Input and Output of Wastewater	Debit	Measured by Environmental Agency of North Sumatera Province
		Sludge	Quantity Generated	Estimation
		CO_2, CH_4, N_2O (from biogenic emissions)	Quantity Generated	Estimation
7	Skimming Tank	Input and Output of Wastewater	Debit	Measured by Environmental Agency of North Sumatera Province
8	Aerated Pond	Input and Output of Wastewater	Debit	Measured by Environmental Agency of North Sumatera Province
		Sludge	Quantity Generated	Estimation
		Electricity	Quantity Used	Direct from IPAL Cemara
		Diesel and Lubricant Consumption	Quantity Used	Direct from IPAL Cemara
		Oxygen	Quantity Used	Direct from IPAL Cemara
		CO_2, CH_4, N_2O (from electricity use, biogenic emissions, diesel consumption)	Quantity Generated	Estimation
9	Facultative Pond	Input and Output of Wastewater	Debit	Measured by Environmental Agency of North Sumatera Province
		Sludge	Quantity Generated	Estimation
		CO_2, CH_4, N_2O (from biogenic emissions)	Quantity Generated	Estimation
10	Sludge Drying Beds	Electricity	Quantity Used	Direct from IPAL Cemara
		Diesel and Lubricant Consumption	Quantity Used	Direct from IPAL Cemara
		Dry Sludge	Quantity Generated	Estimation
		CO_2, CH_4, N_2O (from electricity use, diesel consumption)	Quantity Generated	Estimation
11	Disposal of Dry Sludge	Constituents of disposed dry sludge	Quantity Generated	Measured by Environmental Agency of North Sumatera Province
12	Release of Wastewater Effluent	Input and Output of Wastewater	Debit	Measured by Environmental Agency of North Sumatera Province
		Constituents of treated wastewater effluent	Quantity Generated	Measured by Environmental Agency of North Sumatera Province

- The electricity-specific emission factors for grid electricity of Indonesia are : 6.8E-01 $kgCO_2/kWh$ for CO_2, 1.45E-05 $kgCH_4/kWh$ for CH_4, and 7.8E-06 kgN_2O/kWh for N_2O (Brander, 2011).
- The emission factor of sludge is 0.4 tonnes CO_2-eq. (Australian National Greenhouse Accounts, 2015).
- Formula for estimating fuel combustion of diesel (Australian National Greenhouse Accounts, 2015) :

  $$Eij = \frac{Qi \; x \; ECi \; x \; EFijoxec}{1000} \quad (1)$$

  Whre Eij is the emission of gas type (j) , (carbon dioxide, methane or nitrous oxide, from fuel type (i) (CO_2-e tonnes), Qi is the quantity of diesel (Kilolitres) combusted for stationary energy purposes, ECi is the energy content factor of diesel (Gigajoule per Kilolitre) for stationary energy purposes, ECi Diesel equal to 38.6 Gj/kL, EFijoxec is the emission factor for each gas type (j) (which includes the effect of an oxidation factor) for diesel (Kilograms CO2-eq. per gigajoule), EF CO_2 = 69.9, EF CH_4 = 0.1, EF N_2O = 0.2.
- Aerobic wastewater treatment systems produce primarily CO_2, whereas anaerobic systems produce a mixture of CH_4 and CO_2. Following equations provide a general means of estimating the CO_2 and CH_4 emissions directly from any type of wastewater treatment process assuming all organic carbon removed from the wastewater is converted either CO_2, CH_4, or new biomass (RTI International, 2010).

  $$CO_2 = 10^{-6} \times Q_{ww} \times OD \times Eff_{OD} \times CF_{CO2} \times [(1-MCF_{ww} \times BG_{CH4})(1-\lambda)] \quad (2)$$

  $$CH_4 = 10^{-6} \times Q_{ww} \; x \; OD \times Eff_{OD} \times CF_{CH4} \times [(MCF_{ww} \times BG_{CH4})(1-\lambda)] \quad (3)$$

  Where CO_2 is CO_2 emission rate ($MgCO_2/hr$), CH_4 is CH_4 emission rate ($MgCH_4/hr$), 10^{-6} is Units conversion factor (Mg/g), Q_{ww} is wastewater influent flow rate (m^3/hr), OD is Oxygen demand of influent wastewater to the biological treatment unit determined as either BOD_5 or COD (mg/L), Eff_{OD} is Oxygen demand removal efficiency of the biological treatment unit, CF_{CO2} is Conversion factor for maximum CO_2 generation per unit of oxygen demand equal to 44/32 or 1.375 gCO_2/g oxygen demand, CF_{CH4} is Conversion factor for maximum CH_4 generation per unit of oxygen demand equal to 16/32 or 0.5 gCH_4/g oxygen demand, MCF_{WW} is Methane correction factor for wastewater treatment unit, indicating the fraction of the influent oxygen demand that is converted in anaerobic condition in the wastewater treatment unit, CF is aerated treatment process equal to 0, MCF is anaerobic treatment process equal to 0.8, MCF facultative lagoon, deep (≥ 2 m deep) equal to 0.2, BG_{CH4} is Fraction of carbon as CH_4 in generated biogas (default is 0.65), λ is Biomass yield (g C converted to biomass/g C consumed in the wastewater treatment process), λ aerated treatment process equal to 0.65, λ anaerobic treatment process equal to 0.1, λ facultative lagoon, deep (≥ 2 m deep) equal to 0
- The wastewater treatment process (aerobic, anaerobic, or combination of aerobic and anaerobic) will affect the magnitude of the N_2O emissions. This equation using to estimate N_2O emissions for both aerobic and anaerobic process using an average value for percent of influent TKN emitted as N_2O (RTI International, 2010).

  $$N_2O = Qi \times TKN \times EF_{N2O} \times \frac{44}{28} \times 10^{-6} \quad (4)$$

  Where N_2O N_2O is emissions generated from WWTP process, Qi is Wastewater influent flow rate (m^3/hr), TKNi is Amount of TKN in the influent (mg/L), EF_{N2O} is N_2O emission factor (g N emitted as N_2O per g TKN in influent, 0.0050 g N emitted as N_2O/gTKN, 44/28 is Molecular weight conversion, gN_2O

per g N emitted as N_2O, 10^{-6} is Units conversion factor (Mg/g).

- The following equation to estimates sludge production of UASB Reactor, Aerated Pond and Facultative Pond (Andreoli et al, 2007) :
  $P = (Q \times So) \times Y$ (5)
  Where P is Sludge production (kgSS/d), Q is Influent flow (m^3/d), So is Concentration of influent COD (mg/L), Y is Solids production coefficient (kgSS/kgCODapplied) Y UASB Reactor equal to 0.18 kgSS/kgCODapplied Y Facultative Pond equal to 0.22 kgSS/kgCODapplied Y Aerated Pond is equal to 0.3 kgSS/kgCODapplied.
- And this is the equation for estimating dry sludge production of Sludge Drying Beds :
  $X = P \times \text{Solids capture}$ (6)
  Where X is dry sludge production (kgSS/d), P is Sludge production (kgSS/d), Solids capture is equal to 90-98%,
  $\text{Sludge Flow} = \text{SS load}/(\text{Dry Solid}/100) \times \text{Sludge Density}$ (7)
  Where Sludge Flow is in m^3/d, SS load is in kgSS/d, Dry Solid Sludge is in %, and Sludge Density is in kg/m^3.
- Element Concentration of Lubricant consists of 0.0275895% of As^{5+} , 0.0318925% of Cd^{2+}, 0.0000004% of Co, 0.0833855% of Mo, 0.0086207% of Ni^{2+}, 0.0002657% of Pb^{2+}, and 5.2111300% of Zn^{2+}.
- Quantities of residual from Screening vary from 4 to 40 mL/m^3 of wastewater and for Grit Chamber is 4 to 200 mL/m^3 of wastewater (Turovskiy, I.S., 2006).

c. Life Cycle Impact Assessment

There are 7 impact categories are used for analyzing environmental impact of IPAL Cemara. The characterization factors are tracked based on CML Baseline 2001 and all of data processed by Microsoft Excel.

Table 2. Impact Categories and Characterisation Factors

No	Impact Category	Characterisation Factor
1	Abiotic Depletion	ADP_{Fossil} in kgantimony-eq.
2	Climate Change	$GWP_{100\ in}$ $kgCO_2$-eq.
3	Human Toxicity	$HTP_{inf.}$ in kg1,4-dichlorobenzene-eq.
4	Freshwater Ecotoxicity	$FAETP_{inf.}$ in kg1,4-dichlorobenzene-eq.
5	Terrestrial Ecotoxicity	$TAETP_{inf.}$ in kg1,4-dichlorobenzene-eq.
6	Eutrophication	EP in $kgPO_4$-eq.
7	Photo-Oxidant Formation	POCP in kgethylene-eq.

Abiotic Depletion (ADP Fossil) represents the number of diesel and lubricant consumption, Climate Change is measured by the amount of CO2, CH4, and N2O from electricity use, diesel consumption, and biogenic emissions (UASB Reactor, Aerated Pond, Facultative Pond, and Disposal of Dry Sludge). Human Toxicity, Freshwater Ecotoxicity, and Terrestrial Ecotoxicity represent environmental pollution by the constituents of lubricant consumption, wastewater effluent, and disposal dry sludge. Eutrophication measured based on the amount of N_2O from electricity use and biogenic emissions, and constituents of lubricant consumption, wastewater effluent and disposal dry sludge. Photo-Oxidant Formation represents the amount of CH_4 from electricity use and biogenic emissions.

d. Normalization

Normalization is an optional step in LCA that aids in understanding the significance of the impact assessment results. Normalization is conducted by dividing the impact category results by a normalized value (EPA, 2014). Indonesia does not has normalization factor therefore this research use normalization factors of World 2010 (Sleeswijk, 2008).

Table 3. Normalization Factor

No	Impact Category	Normalisation Factor
1	Abiotic Depletion Fossil	7.8E+12 kgSb-eq.
2	Climate Change	4.2E+13 $kgCO_2$-eq.
3	Human Toxicity	8.9E+12 kg1,4-dichlorobenzene-eq.
4	Freshwater Ecotoxicity	3.1E+10 kg1,4-dichlorobenzene-eq.
5	Terrestrial Ecotoxicity	5.1E+10 kg1,4-dichlorobenzene-eq.
6	Eutrophication	3.8E+09 kgP-eq.
7	Photo-Oxidant Formation	2.8E+10 kgNMVOC-eq.

e. Interpretation

Interpretation is based on the result of characterized impact category for analyzing per impact category and also based on normalized impact category for analyzing based on normalized by impact category and normalized by life cycle stage.

Results and Discussion

Quality of Wastewater Effluent

The quality of wastewater effluent is below government standard quality which each parameter is reduced gradually process by process. All parameters have reduction efficiency >90% except fats, oil, and grease however its effluent value already below government standard quality.

Table 4. Comparison the Quality of Wastewater Effluent and Government Standart Quality

No	Parameter	Unit	Standart Quality	Wastewater Influent	Wastewater Effluent	Efficiency (%)
1	Biological Oxygen Demand (BOD)	mg/L	30	326	22.4	93%
2	Chemical oxigen demand (COD)	mg/L	100	639	44	93%
3	Total Suspended Solids (TSS)	mg/L	30	561	5	99%
4	Fats, Oil and Grease	mg/L	5	1.40	0.97	31%
5	pH	-	6-9	6.94	6.92	-
6	Total Coliform	CFU/100mL	3000	651,344	288	100%

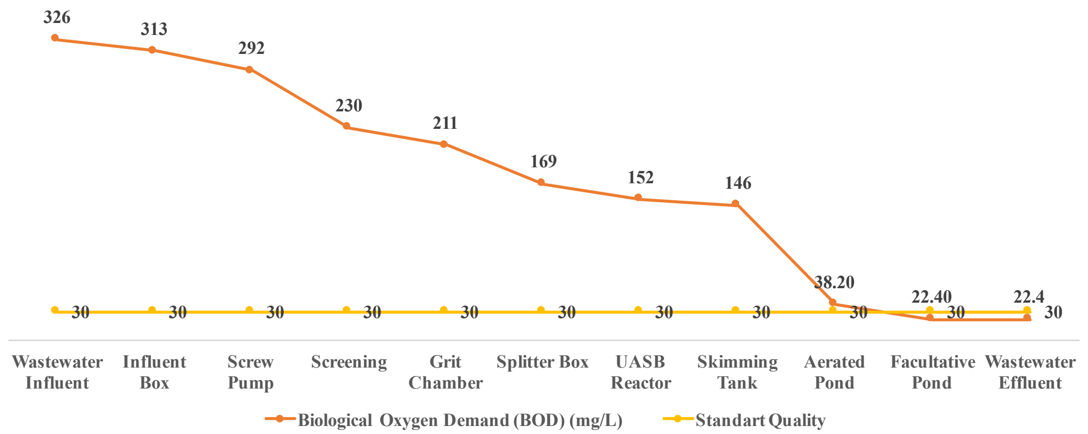

Fig. 1. Actual BOD Comparison to Government Standart Quality

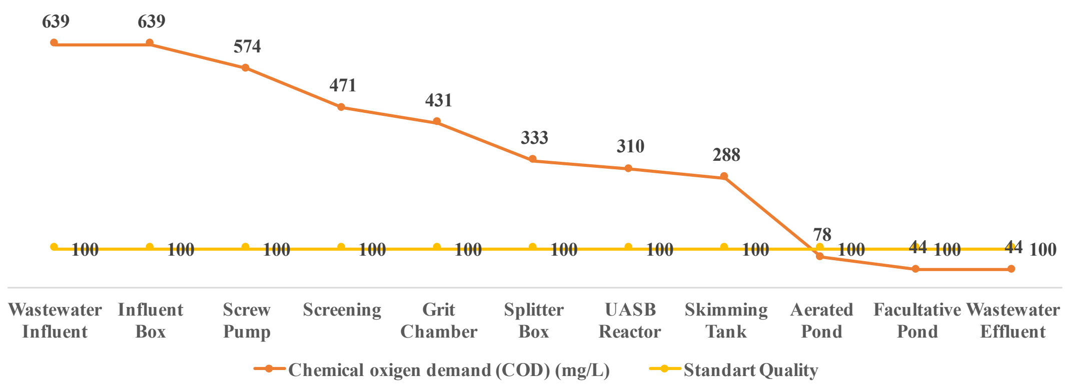

Fig. 2. Actual COD Comparison to Government Standart Quality

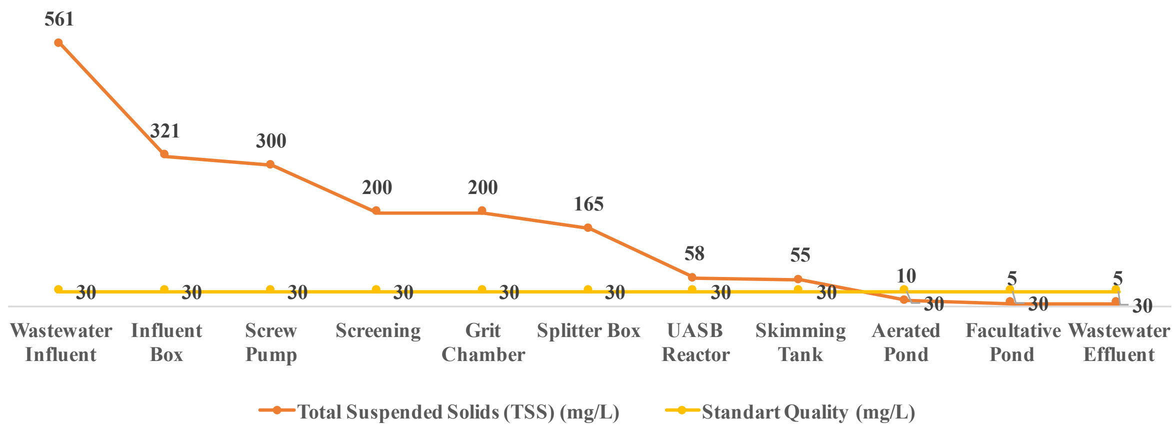

Fig. 3. Actual TSS Comparison to Government Standart Quality

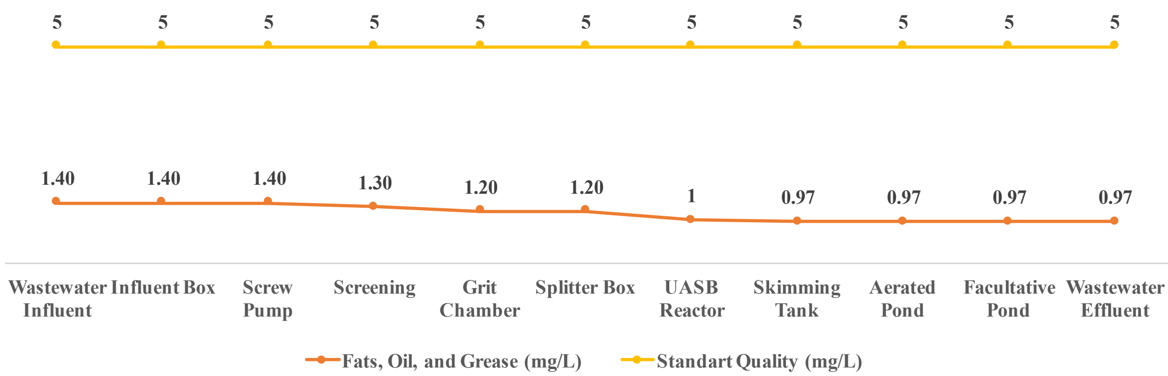

Fig. 4. Actual Fats, Oil, and Grease Comparison to Government Standart Quality

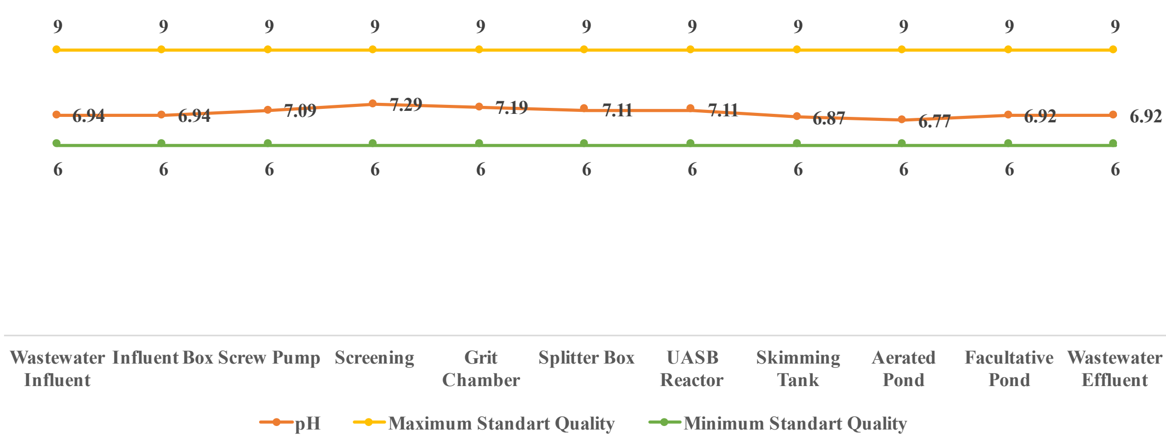

Fig. 5. Actual pH Comparison to Government Standart Quality

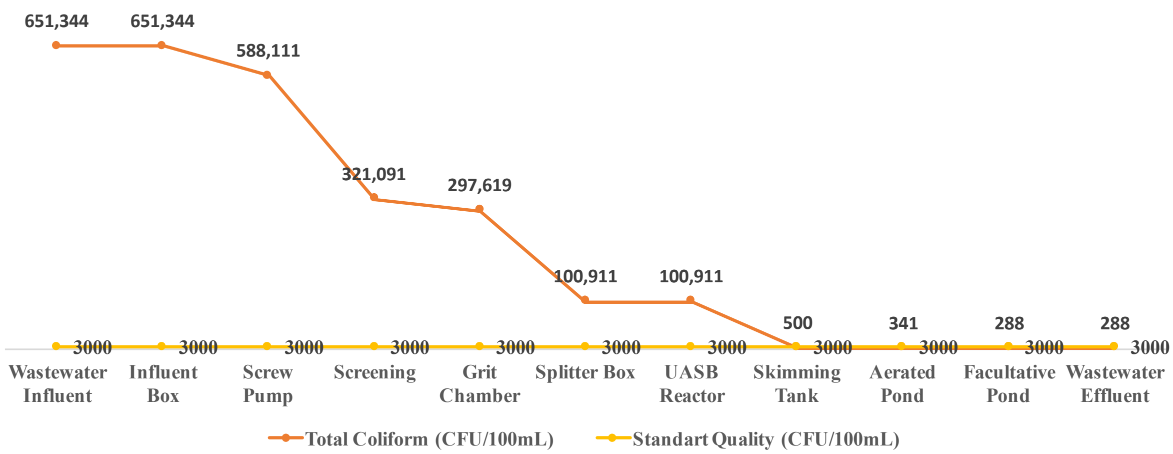

Fig. 6. Actual Total Coliform Comparison to Government Standart Quality

Actual BOD and COD are highly reduced in Aerated Pond up to 74% and 73% respectively, TSS is reduced around 65% in UASB Reactor, Total Coliform is reduced extremely 99% in Skimming Tank, meanwhile Fats, Oil, and Grease and pH are stable reduced in each process even the beginning value (fats, oil, and grease of wastewater influent) is below government standard quality.

Life Cycle Inventory (LCI)

In this research, the LCI is conducted base on the functional unit, which is the treatment of 7,171 m^3 wastewater per day for a year. Flow rate of effluent wastewater is higher 49% than influent wastewater.

Table 5. LCI of Wastewater Debit

No	Life Cycle Stage	Debit of Input (m^3)	Debit of Output (m^3)
1	Influent Box	2,617,488	2,617,488
2	Screw Pump	2,617,488	2,617,488
3	Screening	2,617,488	2,617,488
4	Grit Chamber	2,617,488	2,617,488
5	Splitter Box	2,617,488	2,239,056
6	UASB Reactor	2,239,056	2,428,272
7	Skimming Tank	2,428,272	2,428,272
8	Aerated Pond	2,428,272	5,234,976
9	Facultative Pond	5,234,976	3,901,011
10	Release of Wastewater Effluent	3,901,011	3,901,011

Table 6. LCI of Wastewater Constituents

No	Substance	Unit	Influent Box	Screw Pump	Screening	Grit Chamber	Splitter Box	UASB Reactor	Skimming Tank	Aerated Pond	Facultative Pond	Release of Wastewater Effluent
1	Biological Oxygen Demand (BOD)	kg	853,301	819,274	764,306	602,022	552,290	378,400	369,097	354,528	199,976	87,383
2	Chemical oxigen demand (COD)	kg	1,672,575	1,672,575	1,502,438	1,232,837	1,128,137	745,606	752,764	699,342	408,328	171,644
3	TDS	kg	840,214	785,246	664,842	607,257	463,295	219,427	80,133	67,992	16,804	4,330
4	SS	kg	2,607,018	2,114,930	1,913,384	1,565,258	1,117,667	620,219	242,827	201,547	94,230	39,010
5	TSS	kg	1,468,411	840,214	785,246	523,498	523,498	369,444	140,840	133,555	52,350	19,505
6	Ammonia (NH_3)	kg	69,625	52,612	46,330	46,330	37,692	32,242	24,526	22,826	16,857	6,983
7	Ammonium (NH^{4+})	kg	84,545	67,531	59,417	59,417	48,424	41,423	31,568	29,382	21,673	9,011
8	Carbon Disulfide (CS_2)	kg	4,345	4,345	2,644	2,644	2,879	2,463	2,428	2,185	523	390
9	Hydrogen Fluoride (HF)	kg	2,617	2,617	2,617	2,617	2,617	2,239	2,428	2,428	1,570	780
10	Nitrate (NO^{3-})	kg	4,973	4,973	3,926	3,926	3,141	2,687	2,671	2,428	523	390
11	Nitric Acid (HNO_3)	kg	2,094	1,832	1,832	1,832	1,832	1,567	1,214	1,943	1,047	780
12	Nitrite (NO^{2-})	kg	2,332	2,332	2,233	2,233	2,233	1,910	1,824	2,382	136	74
13	Nitrogen (N)	kg	172,754	143,962	86,377	86,377	86,377	73,889	43,709	48,565	52,350	15,604
14	Phosphate (PO_4^{3-})	kg	5,209	5,444	4,057	4,057	4,057	3,471	2,914	2,914	476	355
15	Phosphoric Acid (H_3PO_4)	kg	7,329	6,805	5,235	5,235	2,617	2,239	3,157	2,671	52	39
16	Phosphorus (P)	kg	1,675	2,199	1,309	1,309	1,309	1,120	947	1,068	152	113
17	Chromium (VI) ion (Cr^{6+})	kg	628	628	497	497	419	381	413	243	52	39

Table 7. LCI of Sludge Production

No	Life Cycle Stage	Sludge Production	Unit	Note
1	Screening	57.58	m^3	Residual production of preliminary treatment
2	Grit Chamber	266.98	m^3	Residual production of preliminary treatment
1	UASB Reactor	111,841	kgSS	Sludge production of secondary treatment
2	Aerated Pond	209,803	kgSS	Sludge production of secondary treatment
3	Facultative Pond	89,832	kgSS	Sludge production of secondary treatment
1	Sludge Drying Beds	105,130	kgSS	Dewatered sludge production

Table 8. LCI of Dry Sludge Constituents

No	Life Cycle Stage	Dry Sludge Amount (kg)	Substance	Mass (kg)
1	Disposal of Dry Sludge	105,130	Nitrogen (N)	1.E-02
			Phosphorus (P)	2.E-03
			Phosphorus(V)oxide (P_2O_5)	3.E-03
			Arsenic (V) ion (As^{5+})	3.E-07
			Cadmium (II) ion (Cd^{2+})	1.E-05
			Chromium (III) ion (Cr^{3+})	5.E-05
			Chromium (VI) ion (Cr^{6+})	8.E-04
			Cobalt (Co)	3.E-07
			Copper (II) ion (CuH_4^{2+})	1.E-05
			Lead (II) ion (Pb^{2+})	3.E-05
			Mercury (II) ion (Hg^{2+})	3.E-07
			Methyl-mercury (CH_3Hg^+)	3.E-07
			Molybdenum (Mo)	3.E-07
			Nickel (II) ion (Ni^{2+})	3.E-05
			Selenium (Se)	3.E-07
			Zinc (II) ion (Zn^{2+})	5.E-05
			Carbondioxide (CO_2)	4.E+04

Table 9. LCI of Electricity Use

No	Life Cycle Stage	Electricity Use (kWh)	CO_2 Emission ($kgCO_{2\text{-eq.}}$)	CH_4 Emission ($kgCH_{4\text{-eq.}}$)	N_2O Emission (kgN_2O-eq.)
1	Screw Pump	116,455	79,736	1.64	0.90
2	Screening	4,134	2,830	0.06	0.03
3	Grit Chamber	10,776	7,378	0.15	0.08
4	Sludge Drying Beds	2,880	1,972	0.04	0.02
5	Aerated Pond	112,834	77,257	1.59	0.87
	Total	**247,078**	**169,174**	**3.48**	**1.92**

Table 10. LCI of Diesel Consumption

No	Life Cycle Stage	Diesel Consumption (kg)	CO_2 Emission ($kgCO_2$-eq.)
1	Screw Pump	137,064	446,400
2	Screening	4,865	15,846
3	Grit Chamber	12,683	41,307
4	Sludge Drying Beds	3,390	11,040
5	Aerated Pond	132,802	432,520
	Total	**290,804**	**947,112**

Table 11. LCI of Oxygen Consumption of Aerator

No	Life Cycle Stage	Oxygen Consumption (kg)
1	Aerated Pond	183,226

Table 12. LCI of Biogenic Emission

No	Life Cycle Stage	CO_2 Emission ($kgCO_{2-eq.}$)	CH_4 Emission ($kgCH_{4-eq.}$)	N_2O Emission (kgN_2O-eq.)
1	Aerated Pond	126,255	0	410
2	Facultative Pond	54,113	21,317	303
3	UASB Reactor	22,477	8,855	579

Table 13. LCI of Lubricant Consumption

No	Life Cycle Stage	Lubricant Consumption (kg)	CO_2 Emission ($kgCO_2$-eq.)	Percentage
1	Screw Pump	2,129	1,276	47%
2	Screening	75	45	2%
3	Grit Chamber	202	121	4%
4	Sludge Drying Beds	52	31	1%
5	Aerated Pond	2,041	1,223	45%
Total		**4,500**	**2697**	**100%**
Lubricant Residue		**3600**		
Lubricant Spill		**180**		

Table 14. LCI of Lubricant Element Concentration

No	Life Cycle Stage	Lubricant Consumption (kg)	Substance	Mass (kg)
1	Screw Pump	85	Arsenic (V) ion (As^{5+})	0.02350046
			Cadmium (II) ion (Cd^{2+})	0.02716571
			Cobalt (Co)	0.00000031
			Molybdenum (Mo)	0.07102692
			Nickel (II) ion (Ni^{2+})	0.00734302
			Lead (II) ion (Pb^{2+})	0.00022632
			Zinc (II) ion (Zn^{2+})	4.43878769
2	Screening	3	Arsenic (V) ion (As^{5+})	0.00082540
			Cadmium (II) ion (Cd^{2+})	0.00095413
			Cobalt (Co)	0.00000001
			Molybdenum (Mo)	0.00249466
			Nickel (II) ion (Ni^{2+})	0.00025791
			Lead (II) ion (Pb^{2+})	0.00000795
			Zinc (II) ion (Zn^{2+})	0.15590227
3	Grit Chamber	8	Arsenic (V) ion (As^{5+})	0.00223105
			Cadmium (II) ion (Cd^{2+})	0.00257901
			Cobalt (Co)	0.00000003
			Molybdenum (Mo)	0.00674303
			Nickel (II) ion (Ni^{2+})	0.00069712
			Lead (II) ion (Pb^{2+})	0.00002149
			Zinc (II) ion (Zn^{2+})	0.42140207
4	Sludge Drying Beds	2	Arsenic (V) ion (As^{5+})	0.00057504
			Cadmium (II) ion (Cd^{2+})	0.00066473
			Cobalt (Co)	0.00000001
			Molybdenum (Mo)	0.00173798
			Nickel (II) ion (Ni^{2+})	0.00017968
			Lead (II) ion (Pb^{2+})	0.00000554
			Zinc (II) ion (Zn^{2+})	0.10861431
5	Aerated Pond	82	Arsenic (V) ion (As^{5+})	0.02252916
			Cadmium (II) ion (Cd^{2+})	0.02604292
			Cobalt (Co)	0.00000030
			Molybdenum (Mo)	0.06809130
			Nickel (II) ion (Ni^{2+})	0.00703953
			Lead (II) ion (Pb^{2+})	0.00021697
			Zinc (II) ion (Zn^{2+})	4.25532766

Analysis of Environmental Impacts Based on Life Cycle Stage

Normalization stage makes these impact categories into the same unit therefore comparison between impacts categories are able to do. These impact categories are analyzed in each life cycle stage and a whole system.

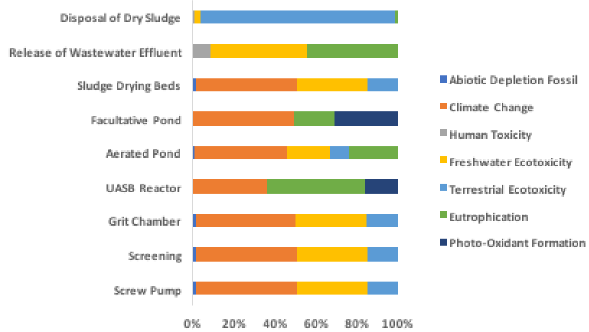

Fig. 7. Analysis Environmental Impacts Based on Life Cycle Stage

- The majority impacts of Screw Pump operational are Climate Change (49.15%), Freshwater Ecotoxicity (34.13%), and Terrestrial Ecotoxicity (15.13%). Climate Change caused by electricity use and diesel consumption, Freshwater and Terrestrial Ecotoxicity caused by lubricant spill of lubricant consumption.
- The majority impacts of Screening operational are Climate Change (49.40%), Freshwater Ecotoxicity (33.94%), and Terrestrial Ecotoxicity (15.05%). Climate Change caused by electricity use and diesel consumption, Freshwater and Terrestrial Ecotoxicity caused by lubricant spill of lubricant consumption.
- The majority impacts of Grit Chamber operational are Climate Change (48.52%), Freshwater Ecotoxicity (34.57%), and Terrestrial Ecotoxicity (15.33%). Climate Change caused by electricity use and diesel consumption, Freshwater and Terrestrial Ecotoxicity caused by lubricant spill of lubricant consumption.
- The impacts of UASB Reactor operational are Eutrophication (48%), Climate Change (36%), and Photo-Oxidant Formation (16%). These 3 impacts are caused by biogenic emission.
- The majority impacts of Aerated Pond are Climate Change (44.62%), Eutrophication (24.15%), Freshwater Ecotoxicity (20.99%), and Terrestrial Ecotoxicity (9.30%). Climate Change caused by electricity use, diesel consumption, and biogenic emission, Freshwater and Terrestrial Ecotoxicity caused by lubricant spill of lubricant consumption.
- The impacts of Facultative Pond operational are Climate Change (49%), Photo-Oxidant Formation (31%), and Eutrophication (20%). These 3 impacts are caused by biogenic emission.
- The majority impacts of Sludge Drying Beds operational are Climate Change (49.40%), Freshwater Ecotoxicity (33.94%), and Terrestrial Ecotoxicity (15.05%). Climate Change caused by electricity use and diesel consumption, Freshwater and Terrestrial Ecotoxicity caused by lubricant spill of lubricant consumption.
- The majority impacts of Release of Wastewater Effluent are Freshwater Ecotoxicity (47.06%) and Eutrophication (44.77%). These impacts caused by the constituents of wastewater effluent.
- The majority impact of Disposal of Dry Sludge is Terrestrial Ecotoxicity (95.32%). This impact caused by the constituents of dry sludge.

Table 15. Normalization Result per Life Cycle Stage

No	Life Cycle Stage	Impact Category	Result of Life Cycle Impact Assessment		Normalisation Factor		Normalized Impact Category (yr)	Percentage (%)
		Abiotic Depletion Fossil	2.8E+03	kgantimony-eq.	7.8E+12	kgSb-eq.	3.6E-10	1.40%
		Climate Change	5.3E+05	$kgCO_2$-eq.	4.2E+13	$kgCO_2$-eq.	1.3E-08	49.15%
		Human Toxicity	2.5E+02	kg1,4-dichlorobenzene-eq.	8.9E+12	kg1,4-dichlorobenzene-eq.	2.8E-11	0.11%
1	Screw Pump	Freshwater Ecotoxicity	2.7E+02	kg1,4-dichlorobenzene-eq.	3.1E+10	kg1,4-dichlorobenzene-eq	8.7E-09	34.13%
		Terrestrial Ecotoxicity	2.0E+02	kg1,4-dichlorobenzene-eq.	5.1E+10	kg1,4-dichlorobenzene-eq	3.9E-09	15.13%
		Eutrophication	2.4E-01	$kgPO_4$-eq.	3.8E+09	kgP-eq.	2.1E-11	0.08%
		Photo-Oxidant Formation	9.8E-03	kgethylene-eq.	2.8E+10	kgNMVOC-eq.	8.5E-13	0.00%
				Total			2.6E-08	100%
		Abiotic Depletion Fossil	9.9E+01	kgantimony-eq.	7.8E+12	kgSb-eq.	1.3E-11	1.41%
		Climate Change	1.9E+04	$kgCO_2$-eq.	4.2E+13	$kgCO_2$-eq.	4.4E-10	49.40%
		Human Toxicity	8.7E+00	kg1,4-dichlorobenzene-eq.	8.9E+12	kg1,4-dichlorobenzene-eq.	9.8E-13	0.11%
2	Screening	Freshwater Ecotoxicity	9.4E+00	kg1,4-dichlorobenzene-eq.	3.1E+10	kg1,4-dichlorobenzene-eq	3.1E-10	33.94%
		Terrestrial Ecotoxicity	6.9E+00	kg1,4-dichlorobenzene-eq.	5.1E+10	kg1,4-dichlorobenzene-eq	1.4E-10	15.05%
		Eutrophication	8.7E-03	$kgPO_4$-eq.	3.8E+09	kgP-eq.	7.5E-13	0.08%
		Photo-Oxidant Formation	3.5E-04	kgethylene-eq.	2.8E+10	kgNMVOC-eq.	3.0E-14	0.00%
				Total			9.0E-10	100%
		Abiotic Depletion Fossil	2.6E+02	kgantimony-eq.	7.8E+12	kgSb-eq.	3.3E-11	1.39%
		Climate Change	4.9E+04	$kgCO_2$-eq.	4.2E+13	$kgCO_2$-eq.	1.2E-09	48.52%
		Human Toxicity	2.3E+01	kg1,4-dichlorobenzene-eq.	8.9E+12	kg1,4-dichlorobenzene-eq.	2.6E-12	0.11%
3	Grit Chamber	Freshwater Ecotoxicity	2.5E+01	kg1,4-dichlorobenzene-eq.	3.1E+10	kg1,4-dichlorobenzene-eq	8.3E-10	34.57%
		Terrestrial Ecotoxicity	1.9E+01	kg1,4-dichlorobenzene-eq.	5.1E+10	kg1,4-dichlorobenzene-eq	3.7E-10	15.33%
		Eutrophication	2.3E-02	$kgPO_4$-eq.	3.8E+09	kgP-eq.	2.0E-12	0.08%
		Photo-Oxidant Formation	9.1E-04	kgethylene-eq.	2.8E+10	kgNMVOC-eq.	7.8E-14	0.00%
				Total			2.4E-09	100%
		Climate Change	4.2E+05	$kgCO_2$-eq.	4.2E+13	$kgCO_2$-eq.	1.0E-08	36%
4	UASB Reactor	Eutrophication	1.6E+02	$kgPO_4$-eq.	3.8E+09	kgP-eq.	1.4E-08	48%
		Photo-Oxidant Formation	5.3E+01	kgethylene-eq.	2.8E+10	kgNMVOC-eq.	4.6E-09	16%
				Total			2.8E-08	100%
		Abiotic Depletion Fossil	2.7E+03	kgantimony-eq.	7.8E+12	kgSb-eq.	3.5E-10	0.873%
		Climate Change	7.5E+05	$kgCO_2$-eq.	4.2E+13	$kgCO_2$-eq.	1.8E-08	44.615%
		Human Toxicity	2.4E+02	kg1,4-dichlorobenzene-eq.	8.9E+12	kg1,4-dichlorobenzene-eq.	2.7E-11	0.07%
5	Aerated Pond	Freshwater Ecotoxicity	2.6E+02	kg1,4-dichlorobenzene-eq.	3.1E+10	kg1,4-dichlorobenzene-eq	8.3E-09	20.99%
		Terrestrial Ecotoxicity	1.9E+02	kg1,4-dichlorobenzene-eq.	5.1E+10	kg1,4-dichlorobenzene-eq	3.7E-09	9.30%
		Eutrophication	1.1E+02	$kgPO_4$-eq.	3.8E+09	kgP-eq.	9.6E-09	24.154%
		Photo-Oxidant Formation	9.5E-03	kgethylene-eq.	2.8E+10	kgNMVOC-eq.	8.2E-13	0.002%
				Total			4.0E-08	100%
		Climate Change	7.3E+05	$kgCO_2$-eq.	4.2E+13	$kgCO_2$-eq.	1.7E-08	49%
6	Facultative Pond	Eutrophication	8.2E+01	$kgPO_4$-eq.	3.8E+09	kgP-eq.	7.1E-09	20%
		Photo-Oxidant Formation	1.3E+02	kgethylene-eq.	2.8E+10	kgNMVOC-eq.	1.1E-08	31%
				Total			3.5E-08	100%
		Abiotic Depletion Fossil	6.9E+01	kgantimony-eq.	7.8E+12	kgSb-eq.	8.9E-12	1.41%
		Climate Change	1.3E+04	$kgCO_2$-eq.	4.2E+13	$kgCO_2$-eq.	3.1E-10	49.40%
		Human Toxicity	6.0E+00	kg1,4-dichlorobenzene-eq.	8.9E+12	kg1,4-dichlorobenzene-eq.	6.8E-13	0.11%
7	Sludge Drying Beds	Freshwater Ecotoxicity	6.5E+00	kg1,4-dichlorobenzene-eq.	3.1E+10	kg1,4-dichlorobenzene-eq	2.1E-10	33.94%
		Terrestrial Ecotoxicity	4.8E+00	kg1,4-dichlorobenzene-eq.	5.1E+10	kg1,4-dichlorobenzene-eq	9.4E-11	15.05%
		Eutrophication	6.0E-03	$kgPO_4$-eq.	3.8E+09	kgP-eq.	5.2E-13	0.08%
		Photo-Oxidant Formation	2.4E-04	kgethylene-eq.	2.8E+10	kgNMVOC-eq.	2.1E-14	0.00%
				Total			6.3E-10	100%
		Human Toxicity	2.8E+06	kg1,4-dichlorobenzene-eq.	8.9E+12	kg1,4-dichlorobenzene-eq.	3.2E-07	8.163043%
8	Release of Wastewater Effluent	Freshwater Ecotoxicity	5.7E+04	kg1,4-dichlorobenzene-eq.	3.1E+10	kg1,4-dichlorobenzene-eq	1.8E-06	47.063386%
		Terrestrial Ecotoxicity	1.9E+00	kg1,4-dichlorobenzene-eq.	5.1E+10	kg1,4-dichlorobenzene-eq.	3.8E-11	0.000955%
		Eutrophication	2.0E+04	$kgPO_4$-eq.	3.8E+09	kgP-eq.	1.8E-06	44.772616%
				Total			3.9E-06	100%
		Human Toxicity	7.4E+00	kg1,4-dichlorobenzene-eq.	8.9E+12	kg1,4-dichlorobenzene-eq.	8.3E-13	0.761%
9	Disposal of Dry Sludge	Freshwater Ecotoxicity	8.7E-02	kg1,4-dichlorobenzene-eq.	3.1E+10	kg1,4-dichlorobenzene-eq.	2.8E-12	2.592%
		Terrestrial Ecotoxicity	5.3E+00	kg1,4-dichlorobenzene-eq.	5.1E+10	kg1,4-dichlorobenzene-eq	1.0E-10	95.317%
		Eutrophication	1.7E-02	$kgPO_4$-eq.	3.8E+09	kgP-eq.	1.4E-12	1.330%
				Total			1.1E-10	100%

Analysis of Normalization Result for a Whole System of IPAL Cemara

According to the normalization result, the analysis of a whole system of IPAL Cemara is able to do. This is analysis of the normalized by impact category and another one is analysis of the normalized by life cycle stage.

Table 16. and Figure 8 display the normalized by impact category of IPAL Cemara. The impact category that gives the largest contribution in IPAL Cemara is Freshwater Ecotoxicity (45.96%) and Eutrophication (44.04%). Freshwater ecotoxicity dominated by the presence of CS_2 (72%) at Release of Wastewater Effluent and Eutrophication dominated by 33% of NH_3 and 32% of N.

Table 4.21. Normalized by Impact Categories of IPAL Cemara

No	Impact Category	Result of Life Cycle Impact		Normalisation Factor		Normalized Impact Category	Percentage
1	Abiotic Depletion Fossil	5.9E+03	kgantimony-eq.	7.8E+12	kgSb-eq.	7.6E-10	0.018707%
2	Climate Change	2.5E+06	kgCO_2-eq.	4.2E+13	kgCO_2-eq.	6.1E-08	1.494151%
3	Human Toxicity	2.8E+06	kg1,4-dichlorobenzene-eq.	8.9E+12	kg1,4-dichlorobenzene	3.2E-07	7.895350%
4	**Freshwater Ecotoxicity**	**5.7E+04**	**kg1,4-dichlorobenzene-eq.**	**3.1E+10**	**kg1,4-dichlorobenzen**	**1.9E-06**	**45.964445%**
5	Terrestrial Ecotoxicity	4.2E+02	kg1,4-dichlorobenzene-eq.	5.1E+10	kg1,4-dichlorobenzene	8.3E-09	0.204223%
6	**Eutrophication**	**2.1E+04**	**kgPO_4-eq.**	**3.8E+09**	**kgP-eq.**	**1.8E-06**	**44.040414%**
7	Photo-Oxidant Formation	1.8E+02	kgethylene-eq.	2.8E+10	kgNMVOC-eq.	1.6E-08	0.382709%
			Total			**4.1E-06**	**100%**

Whereas based on normalized by Life Cycle Stage, Release of Wastewater Effluent (96.73%) is the largest contributor on environmental impact. The detail is displayed by table below.

Table 4.22. Normalized by Life Cycle Stage of IPAL Cemara

No	Life Cycle Stage	Normalized Impact Category (yr)	Percentage
1	Screw Pump	2.6E-08	0.628%
2	Screening	9.0E-10	0.022%
3	Grit Chamber	2.4E-09	0.059%
4	UASB Reactor	2.8E-08	0.694%
5	Aerated Pond	4.0E-08	0.979%
6	Facultative Pond	3.5E-08	0.873%
7	Sludge Drying Beds	6.3E-10	0.015%
8	**Release of Wastewater Effluent**	**3.9E-06**	**96.727%**
9	Disposal of Dry Sludge	1.1E-10	0.003%
	Total	**4.1E-06**	**100%**

Conclusion

From this research, there are some conclusions relates to the operational impact of IPAL Cemara on environment :

1. Aerated Pond has removal efficiency of BOD and COD more than 70%, but on the other hand, it is the largest contributor to Climate Change impact because of diesel consumption (16.97%), the amount of CO_2 (4,95%), and N_2O (4.26%) from biogenic emission, and electricity use (3.04%).
2. The 65% reducing of TSS is occurred in UASB Reactor but UASB Reactor also as contributor for Climate Change impact (16.63%) and Photo-Oxidant Formation impact (29.34%) due to the highest production of CH_4.
3. Facultative Pond contributes 49% of Climate Change impact and 31% of Photo-Oxydant Formation impact because of the highest production of CH_4.
4. Screw Pump and Aerator become the majority of Abiotic Depletion Fossil, Climate Change,

and Terrestrial Ecotoxicity impact because of the higher consumption of diesel and lubricant, and electricity use. Terrestrial Ecotoxicity caused by the lubricant spill from lubricant residue.

5. Based on normalized by impact category, Freshwater Ecotoxicity and Eutrophication is the largest environmental impact in a whole system of IPAL Cemara. Freshwater Ecotoxicity caused by 72% CS_2 at Release of Wastewater and Eutrophication caused by 41.25% of NH_3 and 39.60% of N. It is Align with the result of normalized by Life Cycle Stage, shows that the Release of Wastewater Effluent is the largest contributor to environment in a whole system of IPAL Cemara.

Acknowledgement

Special thank to Mr. Fiza Lubis as Production Head in IPAL Cemara Medan.Thank you for all his precious of time and help. Thank you also to Mr. Faisal, Mr. Fahmi, Dr. Indriyani Rachman, Hafizhul Khair, and Dedi Abdul Hadi.

References

Australian National Greenhouse Accounts. (2015). *Australian National Greenhouse Accounts Factors*, Department of Environment, Commonwealth of Australia, 78 p.

Brander, M.,Sood, A., Wylie, C., Haughton, A., Lovell, J. (2011). Electricity-specific emission factors for grid electricity. Technical paper, *Ecometrica*, 22 p.

Foley, J., de Haas, D., Hartley, K., Lant, P. (2010). Comprehenshive life cycle inventories of alternative wastewater treatment systems. *Water Research*, 44(5), 1654-1666.

Li, Y., Luo, X., Huang, X., Wang, D., Zhang, W. (2013). Life Cycle Assessment of municipal wastewater treatment plant: a case study in Suzhou, China. *Journal of Cleaner Production*, 57, 221-227.

Mcnamara, G., Fitzsimons, L., Horrigan, M., Phelan, T., Delaure, Y., Corcoran, B., Doherty, E., Clifford, E. (2016). Life Cycle Assessment of Waste Water Treatment Plant in Ireland. *Journal of Sustainable Development of Energy, Water and Environment System*, 4(3), 216-233.

N.C. RTI International. (2010, December). *Greenhouse Gas Emissions Estimation Methodologies for Biogenic Emissions from Selected Source Categories : Solid Waste Disposal, Wastewater Treatment, Ethanol Fermentation.* Retrieved from https://www3.epa.gov/ttnchie1/efpac/ghg/GHG_Biogenic_Report_draft_Dec1410.pdf.

Prinajati, P.D. (2020). Domestic Communal Wastewater Treatment Plant Evaluation in Sindangrasa, Bogor, Indonesia. *Journal of Community Based Environmental Engineering and Management*, 4(1), 31-36.

Sleewijk, A.W., Oers, L.F.C.M., Guinee, J.B., Struijs, J., Huijbregts, A.J. (2008). Normalisation in product life cycle assessment: An LCA of the global and European economic systems in the year 2000. *Science in The Total Environment*, 390(1), 227-240.

Turovskiy, I. S. 2006. *Wastewater Sludge Processing.* U.S. : Library of Congress Cataloging –in Publication Data.

Yustiani, Y.M., Pradiko. H., Amrullah, R.H. (2018). The study of deoxygenation rate of Rangkui River water during dry season. *International Journal of Geomate*, 15(47), 164-169.

Zang, Q.H., Wang, X.C., Xiong, J.Q., Chen, R., Cao, B. (2010). Application of life cycle assessment for an evaluation of wastewater treatment and reuse project – Case study of Xi’an, China. *Bioresources Technology*, 101(5), 1421-1425.

http://www.gdrc.org/uem/lca/lca-define.html (accessed March 2017)

https://www.iges.or.jp/en/pub/wastewater-management-systems-indonesia/en (accessed March 2017)