Life-Cycle Assessment of Wastewater Treatment Plant

By

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14791

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

JAN 2015

Universiti Teknologi PETRONAS,

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Perak Darul Ridzuan.

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
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in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CHEMICAL ENGINEERING)

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JAN 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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TUAN MUHAMMAD LUKMANUL HAKIM BIN TUAN YAHYA

ABSTRACT

The life cycle of wastewater treatment plant can have adverse effect on the environment in term depletion of fossil, climate change, resource depletion, ozone layer depletion and cause toxicological effect on human health and ecosystem. This can be resolved using life cycle assessment (LCA) method where the severity of the environmental burden of the wastewater treatment plant can be evaluated. Life Cycle Assessment (LCA) is a method to calibrate and evaluate the environmental impact associated with a service, product or process from cradle-to-grave perspective. The objective of this project is to design the inventory data for the whole process of wastewater treatment plant and evaluate the environmental impact by using the ReCiPe method to conduct the LCA. ReCiPe method is definitely chosen since it has additional advantage compared to other LCA methods. Besides, other LCA methods have a lot of weak points which resulted in less precision of the whole analysis. The scope of the study for this project is focused on the cradle-to-grave approached, which is the assessment is take place from the beginning construction of the wastewater plant until the disposal waste of the wastewater. For the methodology, the LCA of the whole wastewater treatment plant was done by using SimaPro software where it illustrated the environmental burden of the wastewater treatment plant in graphical form. Prior to that, the inventory data for wastewater treatment plant was designed based on the reliable literature review and input into database of the software. Designing of the inventories is the data demanding stage in LCA, as it is the most challenging step in which the data must be evaluated, reviewed and if necessary, corrected to maintain the quality of the result assessment. The study produced 3 categories of results which are midpoint indicators, endpoint damage indicators and single score perspectives. Advance particulars of the project will be described in the subsequent chapters.

ACKNOWLEDGEMENT

All praises to Allah for giving me the opportunity to finally complete this dissertation in time who without His blessings and permission I would never be able to finish this project. First and foremost, I would like to express my gratitude to Chemical Engineering Department of Universiti Teknologi PETRONAS (UTP) for giving me a chance to commence this remarkable Final Year Project (FYP) course as a platform to enhance my knowledge and skills concerning my undergraduate studies in Chemical Engineering all the way through these five years' time. By undertaking this project, I was able to understand the process procedure and skill required in order to conduct a project which has prepared me a better engineering graduate.

Besides, a special thanks to my compassionate supervisor, Dr. Taslima Khanam who is always willing to spend her precious time in assisting me and gave a virtuous support since the early beginning of the project until the completion. Through the weekly meetings and discussions with my supervisor, I have acknowledged various share of insight on the diverse features to be assessed for this project to become feasible. Her brilliance support, effective guidance and patience have brought a great impact to my project. Nevertheless, I would like to thank the Final Year Project (FYP) coordinator and managing committees for arranging numerous seminars as provision and knowledge transfer to assist my work progress in the project. Last but not least, my deepest gratitude goes to my family and friends for giving me endless support all the way through the easy and challenging times. Thank you all.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Wastewater is any kind of water that has been negatively affected in quality by anthropogenic influence, which is mainly caused by human activities. Municipal wastewater is usually transmitted in a sanitary sewer, and treated at a wastewater treatment plant. Wastewater treatment plant basically consists of three phases, primary, secondary and tertiary which involve mechanical, chemical or biological treatment throughout the process stages. Most of the treatment stage applies the gravitational sedimentation to separate the suspended solid which comprised of 70% organic and 30% inorganic solid from the wastewater. Accurate analytical techniques are normally used to measure the strength of wastewater.

The most common indicator used to analyze the characteristics of waste entering and leaving a plant are, Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), pH scale, Total Phosphorus and Total Nitrogen. There are two types of wastewater treatment, Domestic wastewater and Industrial wastewater. Domestic wastewater comprises sewage from rural area such as homes, offices and hotels. While, industrial wastewater is the waste discharge from manufacturing process, as such photo finishing and sugar processes industries. The purposes of wastewater treatment are to remove the organic and inorganic matter consists in the sewage which can cause pollution to the environment. Lundin et al. (2000) stated that the main purposes of wastewater treatment systems are not only to protect the human health and aquatic ecosystems, it beyond to include reducing loss of insufficient resources, minimizing the use of energy and water, lessening waste generation and empowering the recycling of nutrients.

According to Corominas Ll. et al. (2013) Life cycle assessment (LCA) is a tool or technique to specify the impact correlated with a product, a process or a service from cradle-to-grave perspective. LCA had established in 1960s and since then a large number of approaches have been expanded into advance multiple disciplines. In late 1990s, LCA methodologies have been commonly standardized in the International Standard Organization (ISO) 14000 series. LCA analyze the product or service's life cycle started from raw material extraction through material processing, manufacture, distribution, repair and maintenance, until the disposal or recycling phases. There are four basic stages of conducting an LCA, which are Goal and Scope definition, Inventory analysis, Impact assessment and Interpretation. The function of LCA is to assist the decision-makers in selecting the product or process which results in the least impact to the environment.

As a technical approach, LCA for wastewater treatment has been applied in 1990s. According to Guest et al. (2009) and Larsen et al. (2010) LCA is a beneficial technique to enlighten the broader environmental impact of design and operation decisions, in the pursuit of more environmentally sustainable wastewater treatment. Since 1990s, there are more than forty studies have been published and advertised by using an array of databases, boundary conditions and impact assessment methods for interpreting the results in the international peer-reviewed journals (Corominas Ll. et al ,2013). Data for Inventory is collected from lab as well as real industrial wastewater treatment plant, relevant literature and LCA database. The beginning life cycle inventory (LCI) data is commonly compiled straightforwardly from measurements, vendor-supplied information and detailed design documents (Corominas Ll. et al, 2013).

1.2 Problem statement

In regulating the impact assessment of LCA, there are various Life Cycle Impact Assessment (LCIA) methodologies can be applied. These methods could vary in the impact categories they cover, in their selection of indicators and in their geographical focus. Previously in the past years, there have been numerous researches done regarding the life cycle assessment of wastewater treatment plant using methods like Eco-Indicator 99, CML-IA, and TRACI. However, from the literature review analysis found that there has never been a research done on the life cycle assessment of wastewater treatment plant using ReCiPe method. The main reason is, it is a newly developed method which combined the previous Eco-indicator 99 and CML-IA. According to Bengtsson & Howard (2010), ReCiPe is a method that translates life cycle inventory data into a single indicator score value. ReCiPe method has additional advantage in evaluating a process compared to other methods. ReCiPe method has extra impact indicators which covers about 18 categories, thus it has a broader range of environmental impact than any other methods. Certain methodology likes Eco-Indicator 99, CML-IA, and TRACI are very limited in the impact category. Thus, the assessment only represent in certain range of impact which make the assessment less accurate.

Furthermore, some LCA methods are too comprehensive which results in difficulty for government and organizations to evaluate the impacts of process on environment. ReCiPe method would make the assessment perfectly clear by giving a single score value indicator. Acero et. al, (2014) stated that, ReCiPe method evaluates each impact category in 3 different perspectives which are individualist, hierarchist and egalitarian. These perspectives would contribute into a better analysis on the impact compared to other methods. However, the ReCiPe method is not widely used in LCA especially for wastewater treatment plant as compared to other methods. Besides, previous researches had some challenges and difficulties in providing relevant of inventory data for the analysis.

1.3 Aim and Objectives

The aim of this project is to develop the Life Cycle Assessment (LCA) of wastewater treatment plant by using SIMAPRO software and ReCiPe method.

The objectives of this project are:

i) To evaluate the environmental impact of wastewater treatment plant by using ReCiPe method.

ii) To design the inventory data for LCA by collecting the data from real wastewater treatment plant and relevant literature from previous study.

1.4 Scope of study

The scope of this study relies on the method that will be applied to conduct the life cycle assessment.

- The LCA approach will be the ‘cradle-to-grave’ type.
- LCA will be conducted by using software SIMAPRO version 8 and utilizing the ReCiPe method which can translate the result in the form of 18 impact categories.

CHAPTER 2

LITERATURE REVIEW

2.1 Wastewater Treatment Plant

Conventional wastewater treatment consists of a combo of physical or mechanical treatment, chemical and biological processes and operations in order to eliminate the solid suspended, organic matter and some nutrients from wastewater. The treatment level are classified according to the different degrees of treatment, in sequence preliminary, primary, secondary, and tertiary or advanced wastewater treatment.

2.1.1 Preliminary Treatment

The goal for preliminary treatment is to remove the coarse solids and large floating sludge often found in raw wastewater. This removal process is necessary in order to boost the maintenance and process operations of subsequent treatment units. Typically, in preliminary treatment operations might include the grit removal, coarse screening and sometimes, comminution of huge object. However, in most of small wastewater treatment plants, grit removal is not included as a preliminary treatment step. Comminutors are served to reduce the size of large particles sometimes by endorsed to supplement coarse screening, so that they will be eliminated in the form of sludge in subsequent treatment process.

2.1.2 Primary Treatment

In primary treatment, sedimentation process is applied to remove the settleable organic and inorganic solid in wastewater, and the skimming process for removal of floating material (scum). During the primary treatment, approximately 25% to 50% of the incoming Biochemical Oxygen Demand (BOD5), 50% to 70% of the Total Suspended Solids (TSS), and 65% of the oil and grease are removed throughout the treatment. Some materials are also removed during the primary sedimentation such as, organic nitrogen and phosphorus and heavy metals mixed with solids, but colloidal and dissolves constituents are not affected. The primary effluent classified as the effluent from primary sedimentation.

2.1.3 Secondary Treatment

The aim of secondary treatment is to remove the residual organics and suspended solids as the further treatment of the effluent from primary treatment. Secondary treatment, in most of the cases will follows the primary treatment and involves in removal of biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes. In this treatment, some of aerobic biological processes are differing primarily in the behavior in which oxygen is supplied to the microorganisms and in the rate at which organisms metabolize the organic matter.

2.1.4 Tertiary and/or Advance Treatment

Tertiary and/or advanced wastewater treatment is engaged when specific wastewater constituents was failed to be removed by secondary treatment. Advanced treatment or occasionally referred as tertiary treatment when it follows high-rate of secondary treatment. However, sometimes advanced treatment processes are mingled with primary or secondary treatment such as, in chemical addition to primary clarifiers or aeration basin to remove phosphorus.

2.2 Life Cycle Assessment (LCA)

2.2.1 Concept of LCA

Life Cycle Assessment (LCA) is functioned as a tool to evaluate the potential environmental impact of a process, a service, or a product. LCA is also known as 'Life Cycle Analysis' or 'Cradle-to-grave Analysis' (Crawford, 2011). Generally from the name 'Cradle-to-grave' shows the overall process of LCA which comprise the assessment of the entire life cycle of the product, from the beginning of raw materials extraction, through the product fabrication to the disposal of waste. LCA contributes both a holistic representation of comparisons between stages of product life and a product's environmental impact.

2.2.2 LCA Application to Wastewater Treatment Plant

The connections between the treatment process and environmental impacts are the relevant inputs and outputs of the product system (Crawford, 2011). Normally, raw materials and energy are included in the inputs stream. However, outputs may differ extensively, including products, emission to water and radiation to air, sludge and other byproducts. Back in the case of wastewater treatment plants, the wastewater from sewage collection systems, electricity used for mixing and pumping, and other additional chemicals contributes to the major inputs. Besides, outputs consist of treated effluent to the receiving water, diversified gas radiations and sludge.

In order to assess the environmental impact of wastewater treatment plant under the concept of LCA, there are several ways need to be considered. Emmerson et al. (1995) stated that, commonly the life cycle of wastewater treatment plant engages with the construction phase of wastewater treatment plant, production of wastewater phase and the final destruction phase. They also mentioned that both the construction and destruction phase have only a minor impact on the environment within the entire life cycle of the plant. Tillman et al. (1998) have prepared alternatives for wastewater treatment plant in Sweden using the LCA approach. Meanwhile, a case study was conducted by Lassaux et al. (2007) on the anthropogenic water cycle ("from the pumping station to the wastewater treatment plant"). The comparison of environmental impacts between different wastewater treatment plant (Hospido et al., 2008), the assessment of wastewater treatment plant with seasonal variations and the comparison between different LCA methods for wastewater treatment plant (Hospido, 2004) also included as the other analyses of this widely popular topic.

2.2.3 The LCA Framework

A complex life cycle assessment involves a few different stages. The framework for LCA has been standardized by the International Organization for Standardization (ISO) which contains four phases, according to the most updated ISO 14040: 2006;

a. Goal and Scope definition
b. Inventory analysis
c. Impact assessment
d. Interpretation

The goal and scope definition, inventory analysis and impact assessment are worked in sequence, while the interpretation takes place all the way through the process.

2.2.4 Life Cycle Assessment Type

Life cycle philosophy is frequently attributed to as 'cradle-to-grave' approach as it follows a product or a service from sourcing of primary materials ('cradle') to ultimate disposal of waste ('grave'). The study is using the LCA cradle-to-grave type. The system boundary to be analyzed in this study is a treatment plant for wastewater, starting after the influent entrance to the system until before discharge to the receiving body.

2.3 LCA Methods

2.3.1 Eco-indicator 99

Eco-indicator 99 is the replacement of Eco-indicator 95 and has a similarity of method used which is damage-oriented approach. Eco-indicator 99 methodologies' development began with the design of weighting procedure. The resource extractions and emissions are indicated as 10 or more different impact categories include ozone layer depletion, acidification, eco-toxicity, and resource extraction in LCA. The panel found the difficulties in giving the meaningful weighting factors for such a huge number and slightly abstract impact categories.

2.3.2 CML-IA

In 2001, a set of impact categories and characterization methods for the impact assessment was proposed by a group of scientists under the lead of CML (Center of Environmental Science of Leiden University. CML-IA methodology is described for the midpoint approach. Moreover, normalization is presented but there is neither addition nor weighting. The impact categories focused in CML-IA including, depletion of abiotic resources, climate change, stratospheric ozone depletion, human toxicity, fresh-water aquatic eco-toxicity, marine eco-toxicity, terrestrial eco-toxicity, acidification and eutrophication.

2.3.3 TRACI 2.1

TRACI stands for the Tool for the Reduction and Assessment of Chemical and other environmental Impact. TRACI was developed by the U.S. Environmental Protection Agency categorically for the US as a stand-alone computer program by using the input parameters consistent with US locations. The impact categories highlighted in TRACI, including global warming, ozone depletion, eutrophication, acidification, tropospheric ozone (smog) formation, human health criteria-related effect, ecotoxicity, cancer effect human health non-cancer effect, fossil fuel depletion and land-use effects. TRACI is classified as a midpoint oriented Life Cycle Impact Assessment (LCIA) methodology, persistently with EPA's decision not to aggregate between environmental impacts categories.

2.3.4 ReCiPe

ReCiPe method is the successor of the method CML-IA and Eco-indicator 99. Purposely, ReCiPe method was to integrate the 'damage oriented approach' of Eco-indicator 99 and 'problem oriented approach' of CML-IA during earlier development. The 'problem oriented approach' represents the impact categories at a midpoint level. The three impact categories resulted from 'damage oriented approach' of Eco-indicator 99 makes the interpretation of results easier. However, it increases the uncertainty of results. Both highlighted strategies implemented by ReCiPe and had both midpoint (problem oriented) and endpoint (damage oriented) impact categories. ReCiPe consists of two sets of impact categories with correlated sets of characterization factors. 18 impact categories are focused on at the midpoint level. At the endpoint level, three aggregated endpoint categories resulted from the midpoint impact categories and damage factors.

Table 1 Classification of impact categories

Impact Category	Midpoint Indicator	Endpoint Indicator	Characterization factors of Midpoint	Characterization factors of Endpoint
Climate change	Climate change (CC)	Damage to human health (HH) Damage to ecosystem diversity (ED)	$GWP_{x,T} = \frac{\int_0^T a_x \times [x(t)dt]}{\int_0^T a_r \times [r(t)dt]}$	$CF_{HH} = TF \times DF_{HH} = LT_{CO2} \times \frac{dTempt}{\Sigma E_{CO2}} \times \frac{\Delta IMPACT}{\Delta TEMP}$ $CF_{ES} = TF \cdot DF_{ES}$
Ozone depletion	Ozone depletion (OD)	Damage to human health (HH)	ODP	$CF_j = \sum_{S=1}^{8} \frac{\int_{2007}^{2100} \Delta DALY_{j,s} dt}{\int_{2003}^{2040} \Delta OD_j dt}$
Acidification	Terrestrial acidification (TD)	Damage to ecosystem diversity (ED)	$TAP = \frac{FF_x}{FF_{SO_2}}$	$CF_{endpoint,x} = \frac{dSpecies}{dM_X} = SD_{terr} \cdot \sum_j A_j \cdot \frac{dDEP_j}{dM_x} \cdot \frac{dBS_j}{dDEP_j} \cdot \frac{dPDF_{added}}{dBS_j}$
Eutrophication	Freshwater eutrophication (FE) Marine eutrophication (ME)	-	FEP MEP	Unit of endpoint CF : yr / kg
Toxicity	Human toxicity (HT) Terrestrial ecotoxicity (TET) Freshwater ecotoxicity (FET) Marine ecotoxicity (MET)	Damage to human health (HH) Damage to ecosystem diversity (ED)	$F_{j,i,x} = \frac{\partial C_{j,x}}{\partial M_{i,x}}$ $\frac{\partial PDF_{tox}}{\partial C_x} = \frac{\partial PDF_{tox}}{\partial TU_k} \cdot \frac{\partial TU_k}{\partial C_x}$	$CF_{j,i,x} = SD_q \cdot \sum_j CF_{j,i,x} \cdot W_{j \in q}$

Health damage due to PM_{10} and ozone	Photochemical oxidant formation (POF) Particulate matter formation (PMF)	Damage to human health (HH)	$OFP = \frac{dC_{O3}/dM_x}{dC_{O3}/dM_{NMVOC}}$ $PMFP = \frac{iF_x}{iF_{PM10}}$	$CF_{endpoint,x} = \sum_i \left(IF_{pop,x,i} \cdot \sum_e \left(EF_{e,k,i} \cdot DF_{e,k} \right) \right)$
Ionizing radiation	Absorbed dose	Damage to human health (HH)	Ionizing radiation potential (IRP)	Damage to Human Health (HH)
Land use	Agricultural land occupation (ALO) Urban land occupation (ULO) Natural land transformation	Damage to ecosystem diversity (ED)	Each land type has different CF.	Damage to ecosystem diversity (ED) Unit of endpoint CF: yr / m2
Freshwater depletion	Water depletion (WD)	-	Water depletion potential (WDP) Water: $CF_{midpoint}(m^3/m^3) = 1$	-
Mineral resource depletion	Mineral depletion (MD)	Damage to resource cost (RC)	$CF_{c.kg.mid} = -\frac{M_c}{(C_c)^2} \times V_c^2 \times P_{c.kg}$	Damage to resource cost (RC) Unit of endpoint CF: $/ kg
Fossil fuel depletion	Fossil depletion (FD)	Damage to resource cost (RC)	$CF_{midpoint,i} = \frac{CED_i}{CED_{ref}}$	$CF_{kg,oil,end} = MCI_{kg}\ x\ P_{kg} x\ \sum_T \frac{1}{(1-d)^t}$ $CF_{end,i} = CF_{mid,i} x\ CF_{oil,end,kg}$

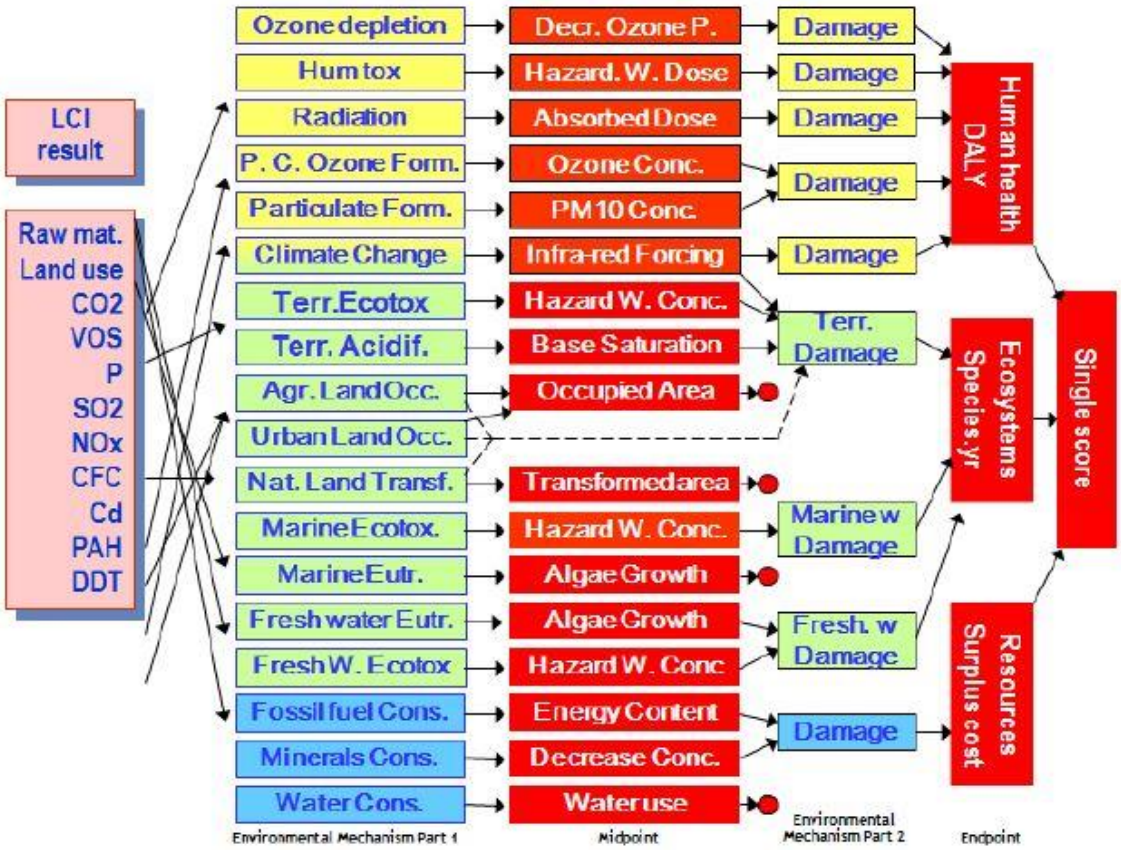

Figure 1 Relationship between the inventory and the midpoint categories (environmental mechanism) and the endpoint categories, including single score (damage model)

CHAPTER 3

METHODOLOGY AND GANTT CHART

3.1 Research Methodology

1. The goal and scope of the LCA were defined.
    a. Set the objective of the study.
    b. Specify the system boundaries from the studies
2. The scope of study was focused on the wastewater treatment plant in Latin America based on the literature review. The study assessed the cradle-to-grave approach.
3. The goal of the study is to evaluate the environmental impact of the wastewater treatment plant in Latin America utilizing the ReCiPe method to conduct LCA.
4. A preliminary research on wastewater treatment system and methods used for LCA was conducted to acquire a better understanding throughout the assessment.
5. The inventories data for the wastewater treatment plant including raw chemical usage, energy consumed, and environmental emission were collected from literatures. The inventories were designed according to the balance of system (BOS) in wastewater treatment system including primary, secondary, and tertiary and sludge treatment system.
6. The inventories found were designed and converted into plant capacity, m^3/year basis in order to standardize the inventories which contains all raw chemical usage, energy consumed and environmental emission for wastewater treatment plant.
7. The conversion was done using the ratio method. The inventories were calculated based on the plant capacity value.
8. A preliminary study on SimaPro software was done to acquire a better understanding throughout the assessment.
9. The LCA on whole system of wastewater treatment plant including all the BOS was done using SimaPro software.

10. The goal and scope ware defined in the software. The preferred library proposed to be applied in the project was selected.
11. Then, all the inventories of the wastewater treatment plant according to the BOS were entered into the SimaPro software. The inventories data were entered according to the process flow of the wastewater treatment system. The output of the system was key-in first by entering its capacity amount and selecting the respective unit. Then, the overall data for the input of the system was entered.
12. The emission to environment of the system were then identified in the software. The inventory for electricity consumed, transport usage and the emission from electricity, waste and transport were also input into the system.
13. The inventory data for overall system of wastewater treatment plant was evaluated using the ReCiPe method by creating a midpoint impact assessment on them. The impact assessment was then translated into 3 damage indicators which are on human health, ecosystem and resource depletion. From that, the single score value was generated in the software.
14. Lastly, a documentation comprising all the findings analysis of information and future recommendations was written.

3.2 Key Milestone

- FYP 1

Week	Activities
Week 1-2	• Understanding the nature of project. • Identify the problem statement, objectives and scope of study.
Week 3-4	• Conduct preliminary studies on existing researches to understand the concept of LCA of wastewater treatment plant. • Find inventories data for the raw material, energy and environment emssion of wastewater treatment and convert them accorrding to plant capacity basis.
Week 5-6	• Conduct preliminary studies on SimaPro and familiarizing with the software by doing the tutorial provided. • Preparation and submission of extended proposal.
Week 7-9	• Start to conduct LCA of wastewater treatment plant using SimaPro software. • Proposal defense.
Week 9-12	• Continuation of project work by using SimaPro software. • Preparation of Final Interim Report.
Week 13-14	• Submission of Final Interim Report

- FYP 2

Week 1-4

- Continue to conduct LCA) wastewater treatment plant.
- Acquire midpoint impact indicator, endpoint damage indicator and single score results.

Week 5-7

- Summary of full results.
- Interpretation and evaluation of the result.

Week 8

- Discuss the results and provide detail reccommendations.
- Submission of Progress Report.

Week 9 -12

- Preparation of Technical Paper and Dissertation .
- Pre-SEDEX presentation.

Week 13-14

- Submission of Technical Paper and softbound and hardbound of Dissertation.
- Project Viva.

3.3 Gantt Chart

- **FYP 1**

No.	Detail	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Title Selection and Supervisor Allocation	■													
2	Understanding the Project	■	■												
3	Identifying the Objectives and Scope of Study		■												
4	Conducting Preliminary Studies on the Project			■	■										
5	Developing Inventories Data			■	■										
6	Conducting Studies on SimaPro Software					■	■								
7	Preparation of Extended Proposal				■	■	■								
8	Submission of Extended Proposal						■								
9	Start Project Work Using SimaPro Software						■	■							
10	Proposal Defense								■	■					
11	Continuation of Project Work								■	■	■	■	■	■	■
12	Preparation of Interim Report										■	■	■	■	
13	Submission of Interim Report														■

- **FYP 2**

No.	Detail	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Conduct LCA On wastewater treatment	■	■	■	■										
2	Evaluation of the result					■	■	■							
3	Analysis and Interpretation of Results						■	■							
4	Conclude the Results with Recommendations								■						
5	Preparation & Submission of Progress Report									■					
6	Preparation of Dissertation									■	■	■			
7	Preparation of Technical Paper									■	■	■	■		
8	Pre-SEDEX											■			
9	Submission of Dissertation													■	
10	Submission of Technical Paper													■	
11	Project Viva														■

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result

The life cycle assessment (LCA) on the wastewater treatment was conducted using SimaPro software where the inventories of the wastewater treatment were entered into the software and analyzed. The ReCiPe method was used in this assessment to analyze the inventories. The inventories data were taken from American literatures. All the inventories data were calculated in yearly basis as per requirement in SimaPro.

In order to design the inventories data for the system, the most important part in LCA is to specify the system boundary and analyze the input and output process. The figure shown below is the system boundary for wastewater treatment plant considering all input and out process.

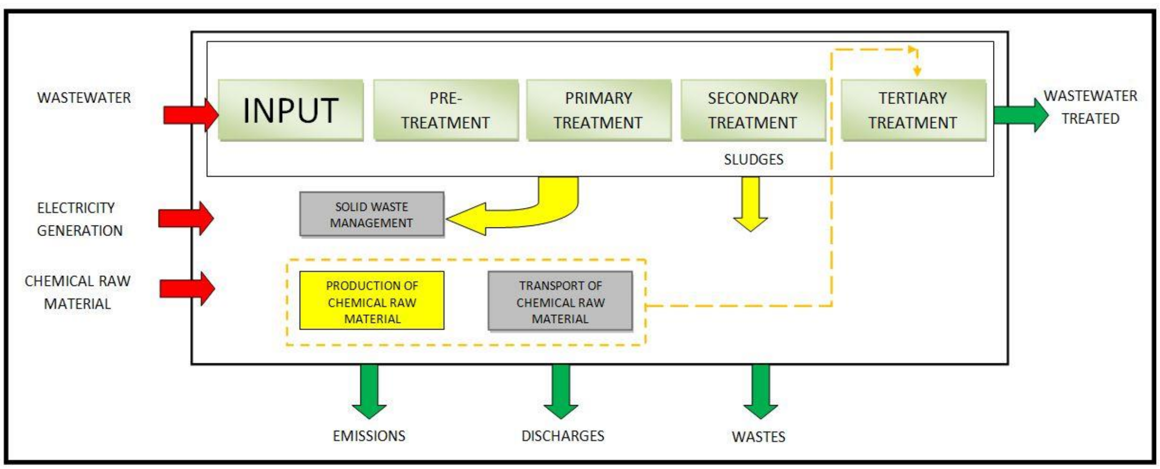

Figure 2 Wastewater treatment system with Input and Output

In this project, the inventories data consist of all elements in life cycle of wastewater starting from construction of wastewater plant and fabrication of equipment, chemical raw materials, energy requirement and emission. Besides, the inventory for balance of system (BOS) for the wastewater treatment plant was divided into 3 subsystems: pre-treatment and primary treatment (Subsystem 1), secondary treatment and tertiary treatment (Subsystem 2), sludge treatment (subsystem 3). All subsystems comprise consumption of electricity and chemical raw material and other waste generated in the wastewater treatment plant. Table 2 shown below gives a detailed description of the subsystems included in wastewater treatment plant.

Table 2 Subsystems included in wastewater treatment plant

Subsystem 1	Subsystem 2	Subsystem 3
Input of raw water Pre-treatment	Secondary treatment	Thickening of secondary sludge
Primary treatment	Tertiary treatment	Dewatering of sludge with centrifugation
Discharge of partially treated water Transportation and treatment of waste	Discharge of treated water	Production and transport of chemical

i. Inventory Data

The inventories data was compiled and collected from the input and output sources for every balance of system (BOS) or sub-system. The inputs of the wastewater treatment plant are wastewater which contains various types of organic matter, nutrients and minerals. The chemical raw material such as Hypochlorite, Sodium Percarbonate and Lime (CaO) functioned as the disinfection and bleaching agent for the system process. Electricity consumed by electrical equipment such as blower and pump. The outputs was measured in three conditions, emission to air, discharge to soil or water and wastes. Wastewater treatment results in the emission of all three of the main Green House Gases (GHG): Carbon dioxide CO_2, Methane (CH_4) and Nitrous Oxide (N_2O). The summary of the most relevant inputs and outputs for the analyzed sub-system were presented in table 3, 4, 5 and 6.

Table 3 Inventory data for subsystem 1

Subsystem 1 (Pre-treatment / Primary Treatment)		
Inputs		
From background function		
Parameters	**Unit**	**Amount**
Electricity consumption	KWh	116070
From upstream function		
Capacity flow rate	m^3/year	4.24E+7
BOD_5	Kg	3.25E+6
COD	Kg	7.95E+6
Nitrates	Kg	1.3E+6
Total Nitrogen	Kg	7.1E+5
Total Phosphorus	Kg	2.5E+5
Total Suspended Solid	Kg	2.9E+6
Outputs		
To subsystem 2		
Capacity flow rate	m^3/year	4.24E+7
BOD_5	Kg	3.25E+6
COD	Kg	7.95E+6
Nitrates	Kg	1.3E+6
Total Nitrogen	Kg	7.1E+5
Total Phosphorus	Kg	2.5E+5
Total Suspended Solid	Kg	2.9E+6

Table 4 Inventory data for subsystem 2

Subsystem 2 (Secondary / Tertiary Treatment)		
Inputs		
From background function		
Parameters	**Unit**	**Amount**
Electricity consumption	KWh	2295850
From subsystem 1		
Capacity flow rate	m^3/year	4.24E+7
BOD_5	Kg	3.25E+6
COD	Kg	7.95E+6
Nitrates	Kg	1.3E+6
Total Nitrogen	Kg	7.1E+5
Total Phosphorus	Kg	2.5E+5
Total Suspended Solid	Kg	2.9E+6
Hypochlorite	Kg	1.16E+5
Sodium Percabonate	Kg	2.93E+5
Lime	Kg	6.6E+3
Outputs		
Emission to water		
Capacity flow rate	m^3/year	2.4E+7
BOD_5	Kg	1.45E+5
COD	Kg	1.27E+6
Nitrates	Kg	1.06+6
Total Nitrogen	Kg	1.7E+5
Total Phosphorus	Kg	1.59E+5
Total Suspended Solid	Kg	2.55E+5
Fats & Oils	Kg	8.6E+4
Emission to air		
CO_2	Kg/ year	23531.915

Table 5 Inventory data for subsystem 3

Subsystem 3 (Sludge Treatment)		
Inputs		
From background function		
Parameters	**Unit**	**Amount**
Electricity consumption	kWh	1606000
From subsystem 1 & 2		
Solid wastes	m^3/year	1.30E+6
Outputs		
Emission to water		
Chrome (Cr)	Kg	1.76E+3
Iron (Fe)	Kg	1.98E+4
Manganese (Mn)	Kg	2.2E+3
Lead (Pb)	Kg	1.89E+3
Cadmium (Cd)	Kg	315.3
Mercury (Hg)	Kg	31.5
Arsenic (As)	Kg	63.07
Total Calcium	Kg	9.65E+5
Total Magnesium	Kg	5.7E+5
Total Sodium	Kg	2.15E+6
Total Potassium	Kg	4.5E+5
Boron	Kg	1.67E+4
Carbonates	Kg	7.14E+6
Emission to air		
Methane (CH4)	Kg/year	52395.75
Nitrogen Oxide	Kg/year	38454
Carbon Dioxide	Kg/year	65681.75

Table 6 Inventory data for construction and equipment fabrication

Construction & Equipment Fabrication			
Subject	**Parameters**	**Unit**	**Amount**
Constructions	Concrete	Kg	7.41E+5
	Grave sand	Kg	2.85E+7
	Diesel Machinery	kWh	4.07E+5
Equipment Fabrication	Electricity	kWh	8.76E+3
	Steel	Kg	1.06E+4

ii. Network

Figure 3 below shows the network or the tree of wastewater treatment plant system where it indicates the combination of plant processes and construction materials to perform the LCA of wastewater treatment plant. The importance of taking the overall process of wastewater treatment plant including the construction and equipment fabrication is due to the cradle-to-grave LCA type.

A complete system of wastewater treatment plant produced about 4.24E+10 kg of wastewater in sub-system 1, 2.48E+10 kg of wastewater in sub-system 2 and 1.3E+10 kg of sludge waste in sub-system 3. The system also considered one (1) unit of construction and equipment fabrication process.

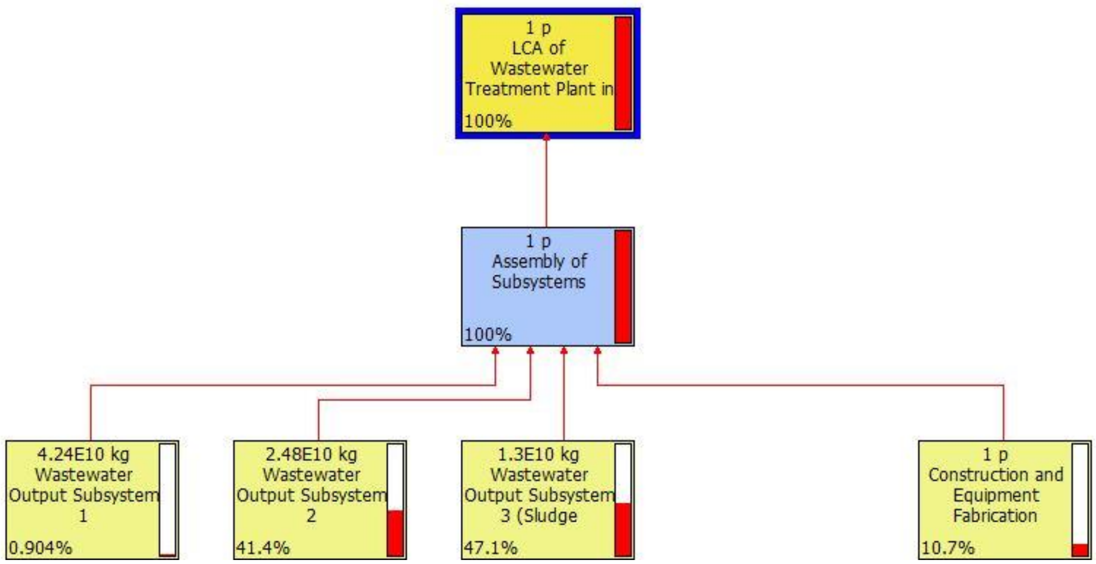

Figure 3 Wastewater treatment system Network

iii. Midpoint Indicator

The midpoint indicator for ReCiPe method contains 18 types of environmental impact. SimaPro software normalizes the data using European normalization in order to get magnitude for environmental impact.

In normalization process, the quantity of parameter that contributed towards the impact category is divided with a normalization reference. The normalization reference value is the average of yearly environmental burden in a country or a continent. After the normalization process, the impact indicator will be dimensionless figure which specifies the magnitude if each impact indicator. Resulted from this, the impact indicators can be simply compared with one another.

Figure 4 shows the graph of normalized midpoint impact indicator for complete wastewater treatment system with its balance of system (BOS) and construction part. As refer to figure 4, the life cycle of wastewater treatment contributes highest towards the fossil depletion which has a value of 572.8 and climate change which has a value of 374.9 compared to other impact indicators. The lowest severity of impact indicators is the contribution towards ozone depletion which is around 0.0159.

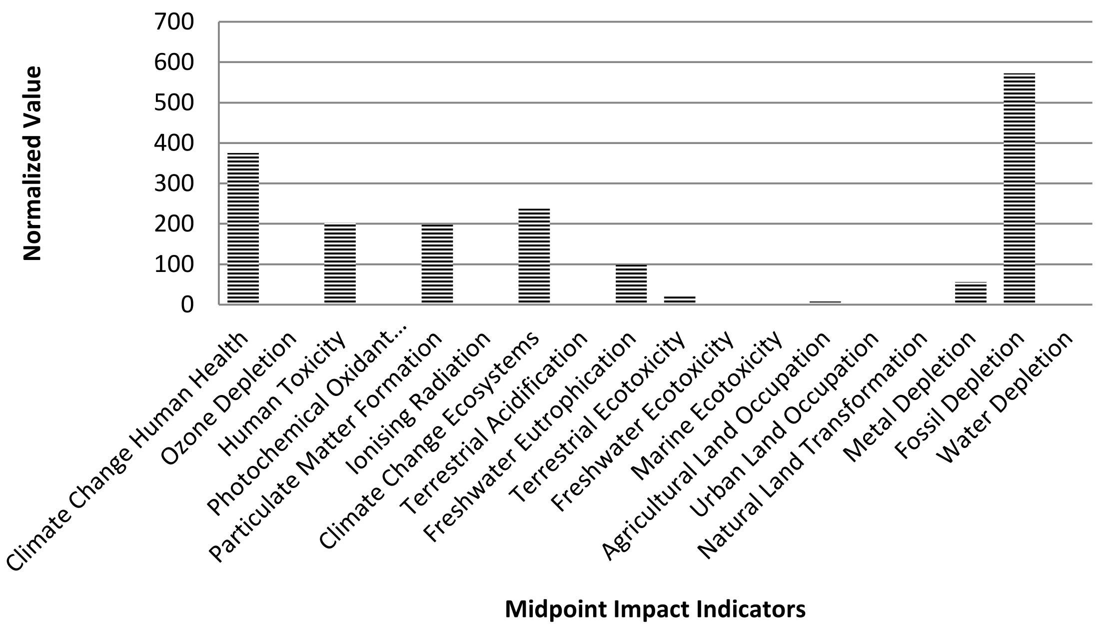

Figure 4 Normalized midpoint impact indicator of wastewater treatment plant

The impact indicators of each sub-system were also evaluated to find out the impact of each sub-assembly. Figure 5 demonstrates the graph of midpoint impact indicators for the sub-assemblies. For wastewater output from subsystem 1 (pre-treatment and primary treatment) sub-assembly, it has the highest impact on freshwater eutrophication with value of 61.2 and then lowest impact on photochemical oxidant formation with value of 0.00019. For wastewater output subsystem 2 (secondary treatment and primary treatment) sub-assembly, it has the highest impact on fossil depletion with value of 331.5 and lowest impact on ozone depletion with value of 0.0092. For wastewater output subsystem 3 (Sludge treatment) sub-assembly, it has the highest impact on climate changes with value of 176.4 while the lowest impact on ozone depletion with value of 0.0035. Lastly, for construction and equipment fabrication sub-assembly, it has the highest impact on fossil depletion with value of 63.73, while the lowest impact on marine ecotoxicity with value of 0.0054.

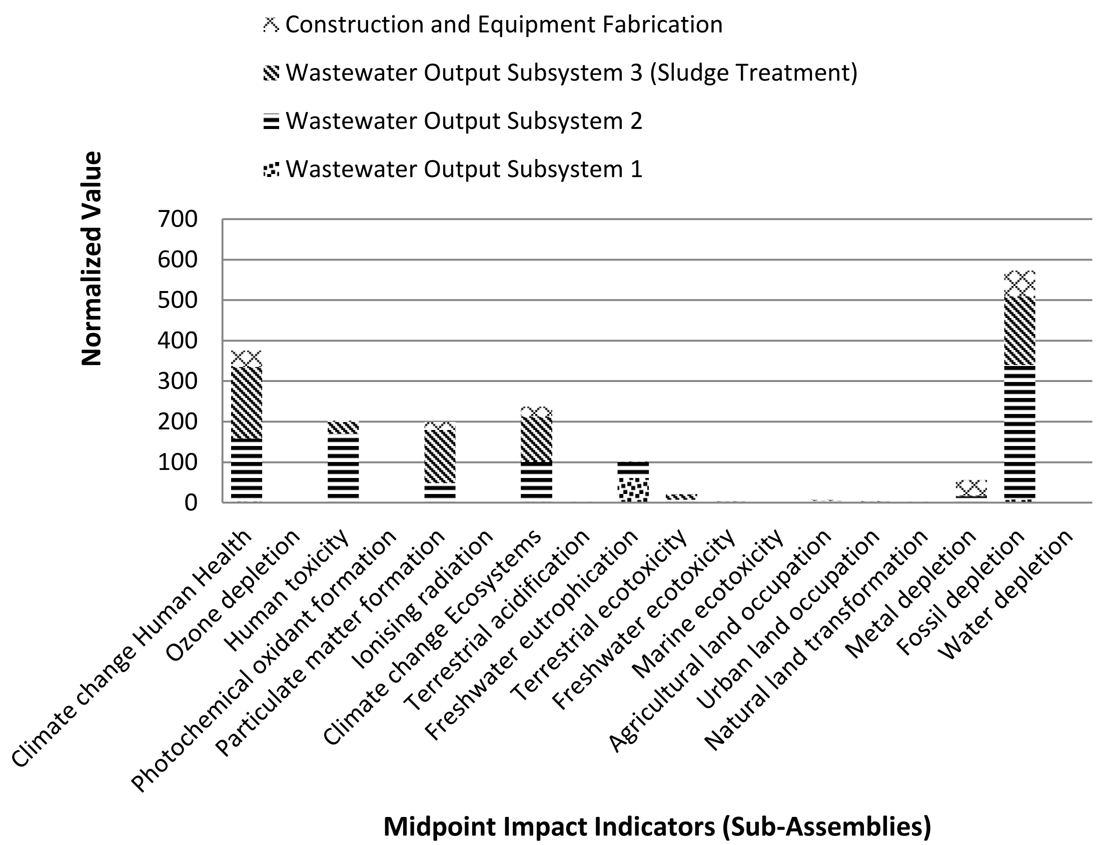

Figure 5 Normalized midpoint impact indicators for Sub-Assemblies of wastewater treatment plant

iv. Endpoint Damage Indicator

For endpoint damage, the data will be converged towards the damages of each impact indicator can cause towards human health, ecosystem and resources. Same as the midpoint indicator, the damage indicator would go through normalization process due to damage indicator cannot be compared to one another without normalization. Figure 6 illustrates the graph of damage indicators of complete wastewater treatment system. Referring to figure 6, the life cycle of wastewater treatment plant has the highest damage towards human health with value of 777.6, followed by resources with value of 629 while the lowest damage is towards the ecosystem with value of 375.5.

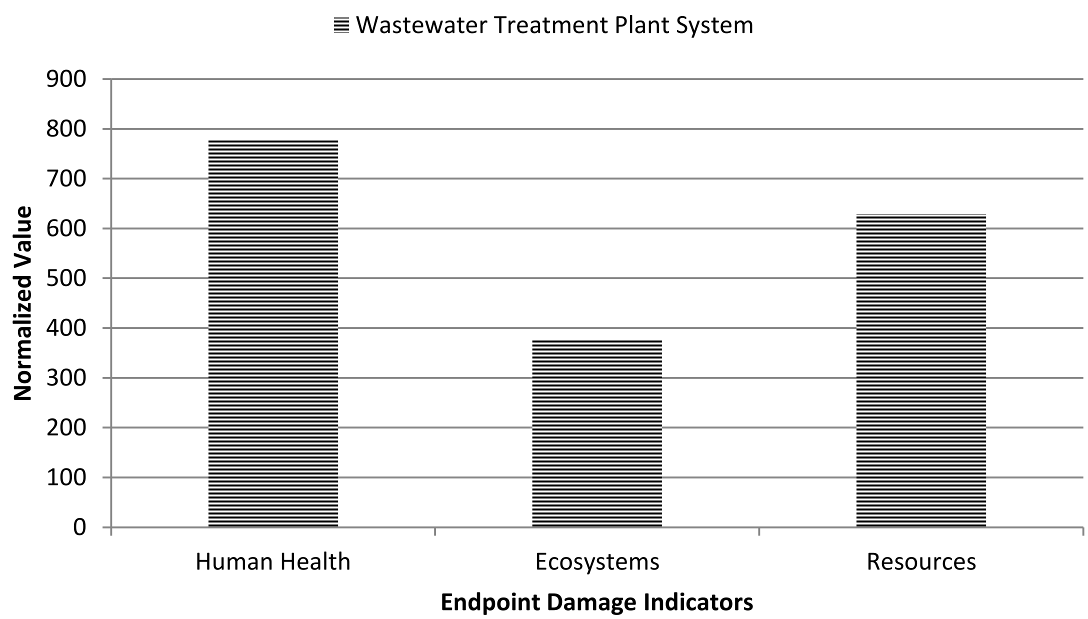

Figure 6 Normalized damage indicators of wastewater treatment plant

The damage assessment for each sub-system also was done to find out the damage of the sub-assemblies cause towards human health, ecosystem and resource. Figure 8 shows the graph of damage assessment for each sub-system. For the damage towards human health, the wastewater output subsystem 2 has the highest contribution with value of 371.7 and wastewater output subsystem 1 has the lowest contribution with value of 4.94.

For the damage towards ecosystem, the wastewater output subsystem 2 has the highest contribution with value of 154.6 and construction and fabrication has the lowest contribution with value of 29.08. Finally for the damage towards resource, the wastewater output subsystem 2 has the highest contribution with value of 347.6 and wastewater output subsystem 1 has the lowest contribution with value of 8.14.

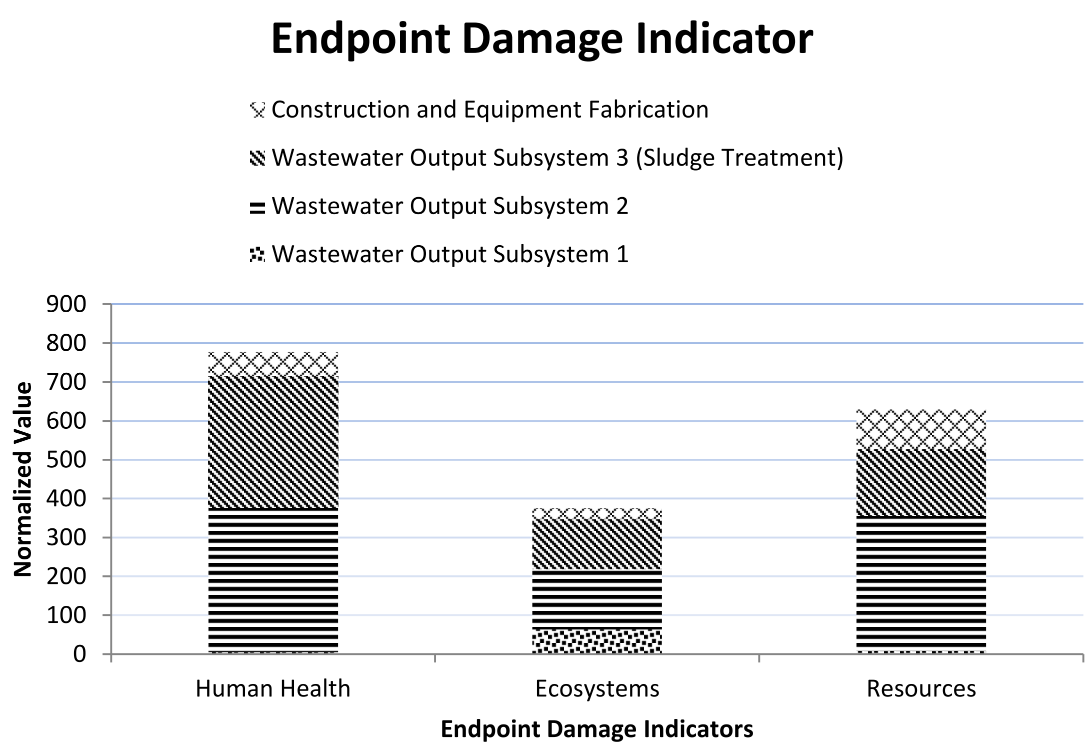

Figure 7 Normalized damage indicators for sub-assemblies of wastewater treatment plant

v. Single score

The damage indicators would then go through weighing process where each of the damage indicators is combined with the weighing factor to form a single score for the system. The data is symbolized in the unit of Kilo-point (kPt). The single score is usually applied to compare one product or process from another. The single score was evaluated in 3 categories of perspectives which are hierarchist, individualist and egalitarian. These 3 perspectives illustrate a set of choices on issues such as expectations on appropriate management or future technology development that can avoid future damages.

Figure 8 demonstrates the single score of 3 perspectives. Firstly, hierarchist perspective which is the most common policy principle with regards to time-frame. It has a total score of 612 kPt. The single score is a summing up of damage score where damage towards human health has an indicator score of 345 kPt, damage towards ecosystem has the score of 29 kPt, while the damage score towards resource has a score of 237 kPt.

Next, individualist is based on short term significance, impact types that are acknowledged, technological optimism as regards human adaption. The figure 8 illustrates that the individualist perspective has a score of 796 kPt. The damage towards human health specified the score of 620 kPt, damages towards ecosystem has the score of 28 kPt, and the damage towards resource has a score of 148 kPt.

The last perspective is egalitarian. Egalitarian is the most precautionary perspective which considered as the longest time-frame. For egalitarian perspective which has a total score of 1601 kPt, has the score of 1410 kPt for human health, 32 kPt score for ecosystem and 158 kPt score for resource. This proves that as the time frame increases, the production of wastewater treatment system would cause a higher damage towards human health.

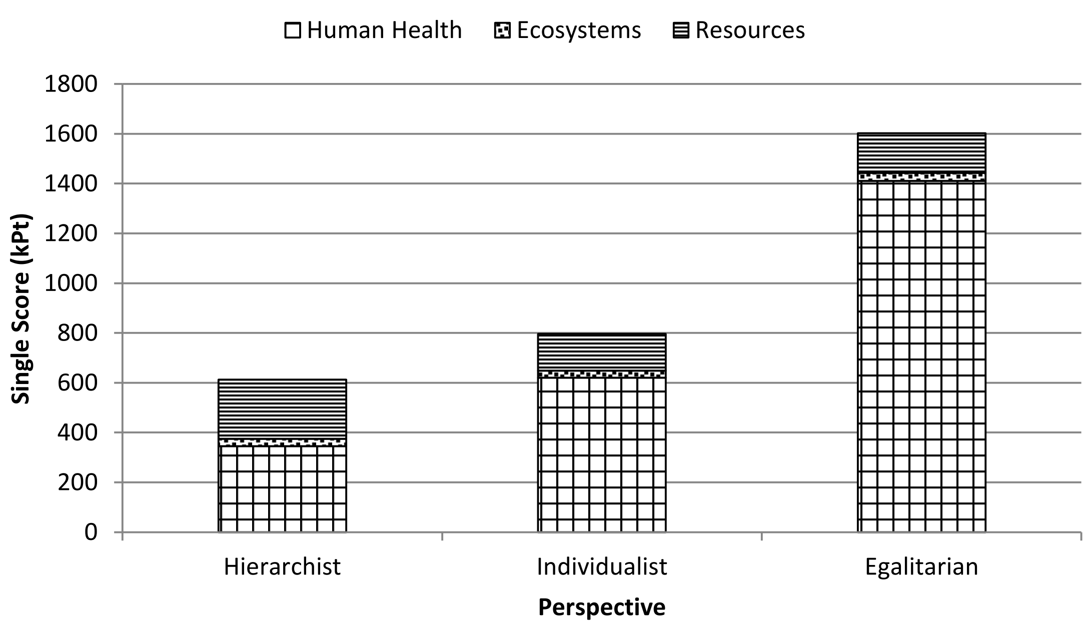

Figure 8 Single score based on perspective for wastewater treatment plant

The single score evaluation for each sub-system also was performed. Figure 9 shows the graph of single score for sub-system. The assessment was prepared based on hierarchist perspective. Wastewater output sub-system 1 has a score of 10.2 kPt, with a human health score of 2.2 kPt, ecosystem score of 5 kPt, and resource score of 3 kPt. Wastewater output subsystem 2 has a score of 308 kPt, with a human health score of 165 kPt, ecosystem score of 12 kPt, and resource score of 131 kPt. For wastewater output subsystem 3 (Sludge treatment) has a score of 225 kPt, with a human health score of 150 kPt, ecosystem score of 10 kPt, and resource score of 64 kPt. Lastly, construction and equipment fabrication sub-assembly has a score of 68 kPt, with a human health score of 27 kPt, ecosystem score of 2.3 kPt, and resource score of 38 kPt. The graph indicates that the wastewater output subsystem 2 has the highest damage score and wastewater output subsystem 1 has the lowest damage score.

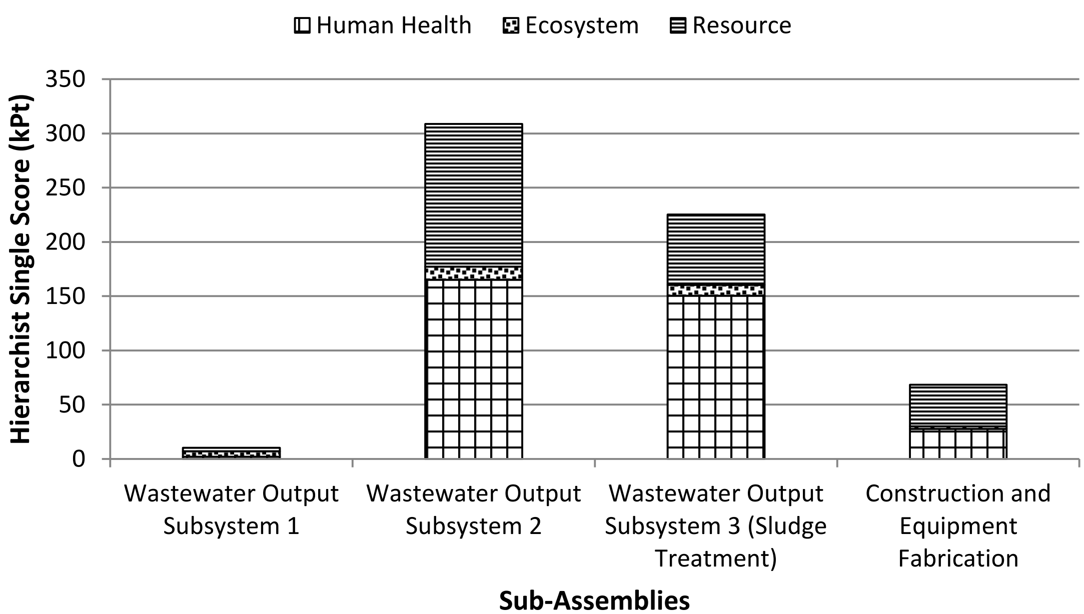

Figure 9 single score (Hierarchist) for sub-assemblies of wastewater treatment plant

For individualist perspective, Wastewater output sub-system 1 has a score of 8.56 kPt, with a human health score of 3.3 kPt, ecosystem score of 3.6 kPt, and resource score of 1.6 kPt. Wastewater output subsystem 2 has a score of 332 kPt, with a human health score of 247 kPt, ecosystem score of 9.2 kPt, and resource score of 75 kPt. For wastewater output subsystem 3 (Sludge treatment) has a score of 376 kPt, with a human health score of 328 kPt, ecosystem score of 13 kPt, and resource score of 34 kPt. Lastly, construction and equipment fabrication sub-assembly has a score of 79 kPt, with a human health score of 41 kPt, ecosystem score of 1.6 kPt, and resource score of 36 kPt. The figure 10 indicates that the wastewater output subsystem 3 has the highest damage score and wastewater output subsystem 1 has the lowest damage score.

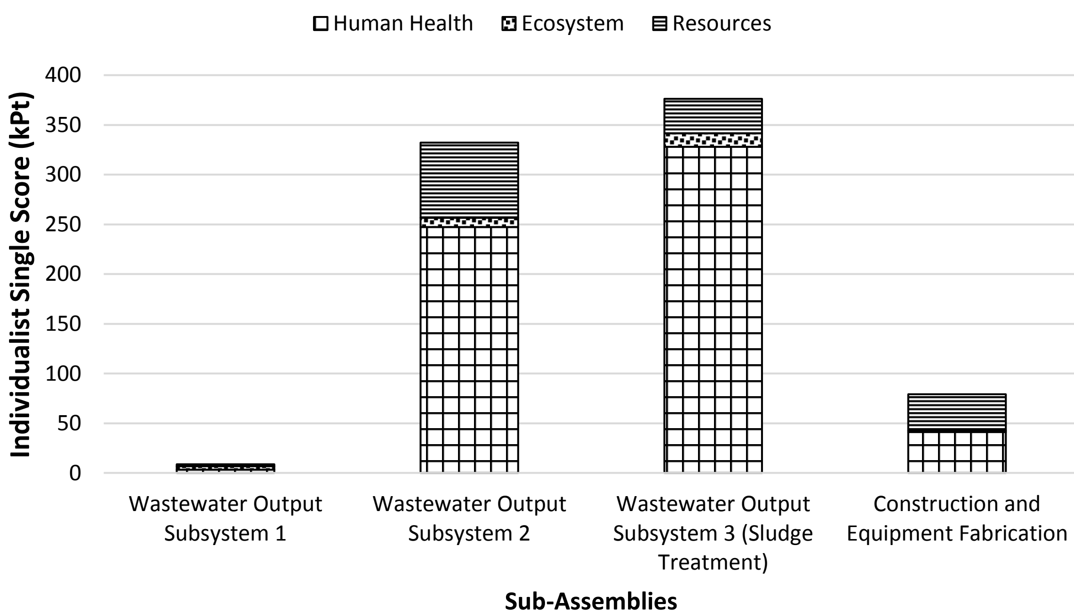

Figure 10 Single score (Individualist) for sub-assemblies of wastewater treatment plant

For Egalitarian perspective, Wastewater output sub-system 1 has a score of 16 kPt, with a human health score of 11 kPt, ecosystem score of 2.5 kPt, and resource score of 2 kPt. Wastewater output subsystem 2 has a score of 589 kPt, with a human health score of 488 kPt, ecosystem score of 13 kPt, and resource score of 87 kPt. For wastewater output subsystem 3 (Sludge treatment) has a score of 915 kPt, with a human health score of 858 kPt, ecosystem score of 13 kPt, and resource score of 43 kPt. Lastly, construction and equipment fabrication sub-assembly has a score of 80 kPt, with a human health score of 51 kPt, ecosystem score of 3.2 kPt, and resource score of 25 kPt. The figure 11 indicates that the wastewater output subsystem 3 has the highest damage score and wastewater output subsystem 1 has the lowest damage score.

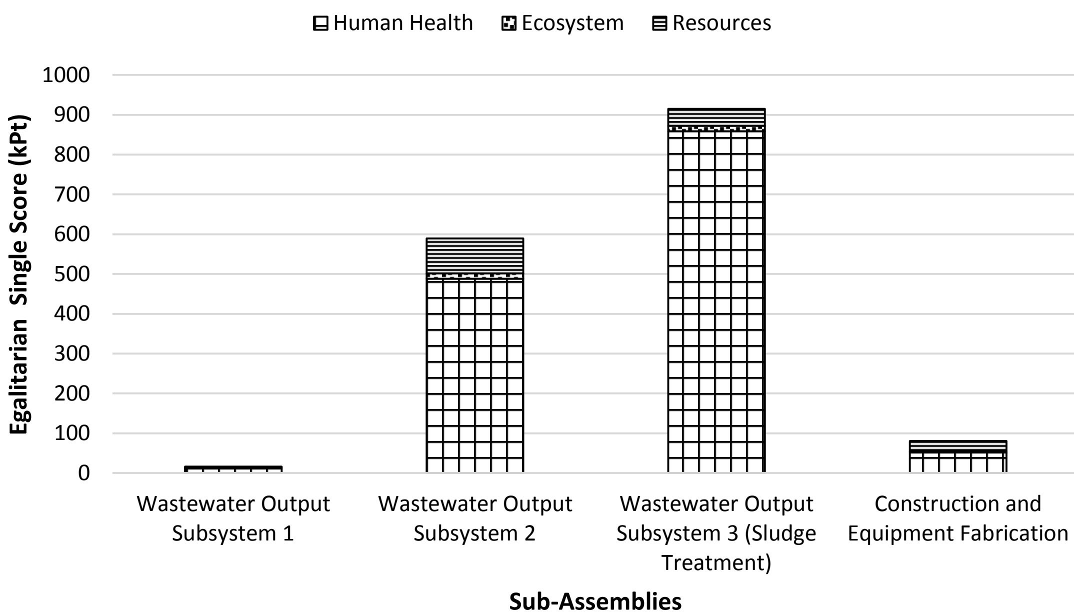

Figure 11 Single score (Egalitarian) for sub-assemblies of wastewater treatment plant

4.2 Discussion

Referring to the figure 4, normalized midpoint impact indicator of wastewater treatment plant, the largest impact of wastewater toward the environment is fossil depletion. Word fossil fuel associates to a group of resources that consists of hydrocarbons. The midpoint characterization factor is based on the energy content in wastewater treatment plant. The main resources that contribute to the fossil depletion are high voltage of electricity, sodium percarbonate as surfactant agent, lime (Calcium Oxide), construction steel, diesel machinery and construction concrete. The biggest contribution toward the fossil depletion is from the wastewater output subsystem 2 which is secondary and tertiary treatment.

The second highest impact of wastewater treatment plant toward the environment is climate change. Climate change is a long-term swing in weather circumstances identified by changes in temperature precipitation, winds and other indicators. This impact can be caused by human activities such as burning of fossil fuels, and conversion of land for agriculture and forestry that might release the Green House Gases (GHG) such as Carbon Dioxide and Methane (CH_4). This GHG will build up in the atmosphere and led to an enhancement of the natural greenhouse effect such as climate change. Sludge treatment system (subsystem 3) has the highest contribution toward the climate change due to the high content of solid waste which may led to the release of Methane gas (CH_4). Other factor is the high voltage electricity consumption.

The third largest impact of wastewater treatment plant toward the environment is human toxicity. Human toxicity is calculated by considering the time-integrated fate, exposure of a unit mass of chemical released into the environment. The assessment of effects related to the human toxicity impact category is focused on effect resulting from direct exposure to chemicals. Secondary and tertiary treatment system (subsystem 2) has the highest contribution toward the human toxicity due to the present of high dosage of sodium percarbonate as the surfactant agent for cleaning purposes and detergent in wastewater treatment plant. The other possible factors are lime (CaO) which present in detergent during cleaning process and high voltage of electricity consumption in wastewater treatment plant.

Besides, in endpoint damage indicator point of view, the highest damage caused by wastewater treatment plant is toward the human health. Life cycle assessments generally evaluate damage to human health using the theory of 'disability-adjusted life years' (DALY). The DALY of a disease is calculated from human health statistics on life years for both lost and disabled. According to the figure 7 normalized damage indicators for sub-assemblies of wastewater treatment plant, the highest contributor toward the human health damage is from secondary and tertiary treatment, followed by sludge treatment. Referring to the figure 12, the biggest contributors toward the human health are high voltage of electricity consumption for treatment plant, solid waste production in sludge treatment system and high dosage of sodium percarbonate used as the cleaning agent in secondary treatment.

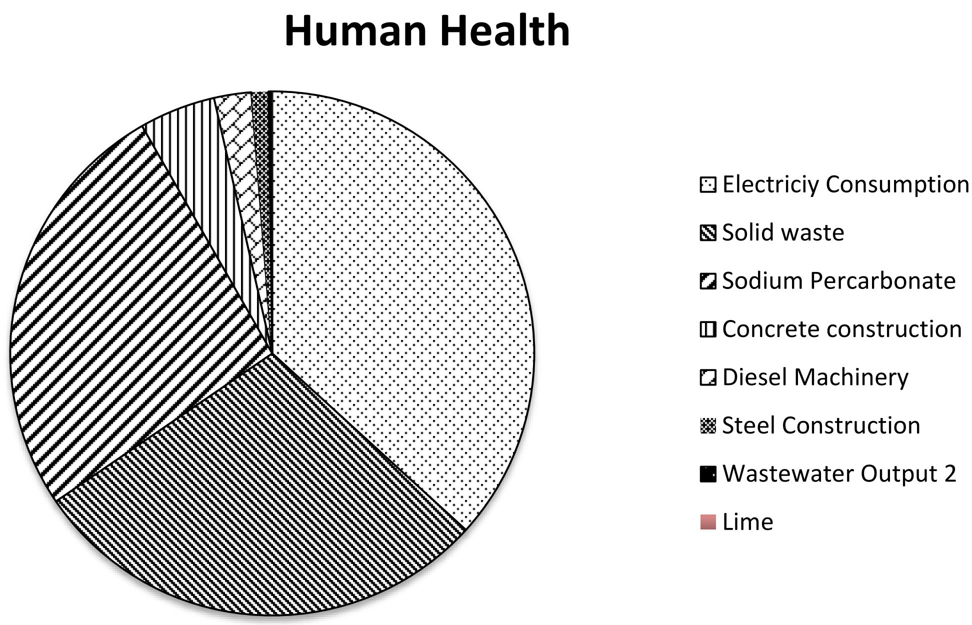

Figure 12 Pie chart of contributor of human health damage

The second largest damage caused by wastewater treatment plant is toward the resource. Often quoted that the mankind will run out of resources for future generations must be taken as an important issue. Several groups believe resource depletion as the only matter to be monitored. In order to understand the resource needs, it is important to differentiate between a material and its function, the necessary property of the material that is used to supply a certain purpose. According to figure 7, the main contributors to resource damage are secondary and tertiary treatment and sludge treatment system. Referring to figure 13, high voltage of electricity consumption in treatment plant, used of high dosage of sodium percarbonate as cleaning agent in secondary treatment and steel and concrete construction are the main contributor to the resource depletion damage.

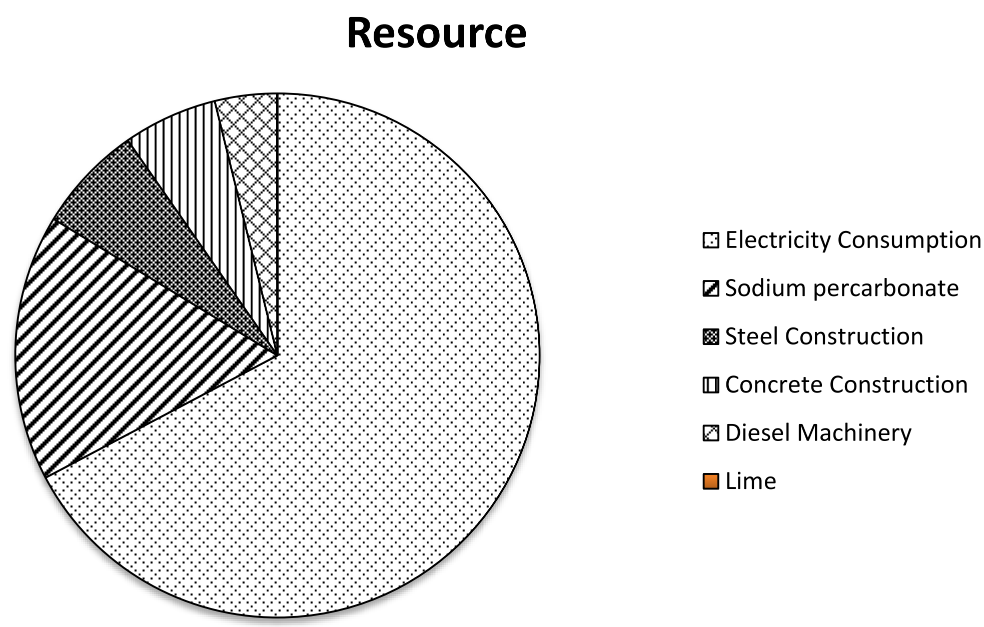

Figure 13 Pie chart of contributor of resource damage

Lastly, the ecosystem damage indicator. Ecosystems are heterogeneous and very difficult to monitor. An approach to explain ecosystem quality is in term of energy, matter and information flows. When such flows are applied to characterize ecosystem quality, it can be understood that a high ecosystem quality is the situation that allows flows to take place without noticeable disruption by anthropogenic activities. On the contrary, a low ecosystem quality is the state in which these flows are disrupted by anthropogenic activities. Therefore, the level of the disruption is the most essential parameter to measure the ecosystem quality. According to figure 14, high voltage of electricity consumption in treatment plant, sludge production in sludge treatment system, primary, secondary and tertiary output are the main contributors toward the ecosystem damage.

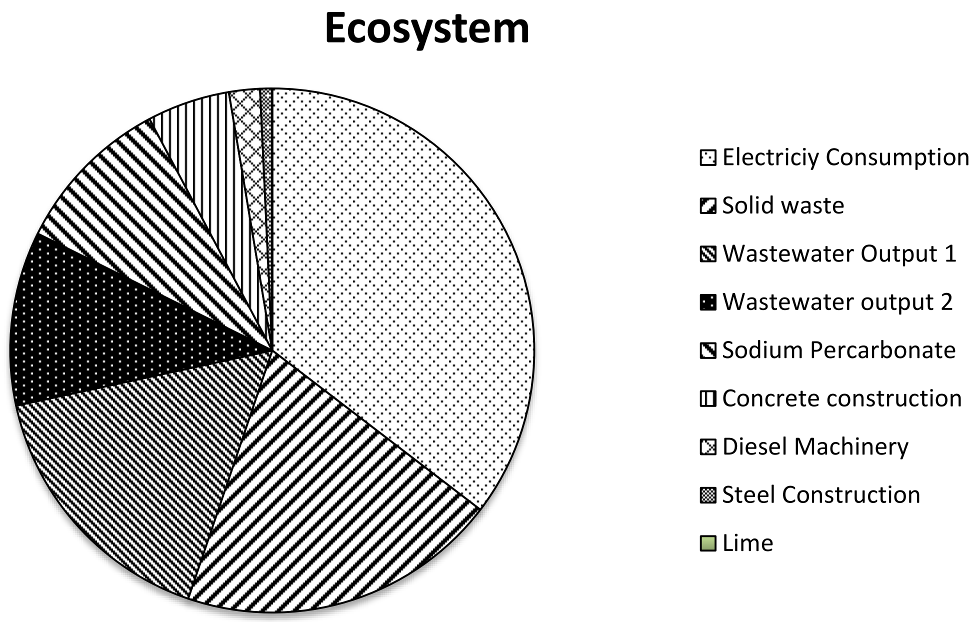

Figure 14 Pie chart of contributor of Ecosystem damage

Electricity is the most significant source of energy in the United States, especially used to power the plant industry like wastewater treatment. According to the Environmental Protection Agency (2012), the combustion of fossil fuels to produce electricity is the greatest single source of CO_2 emissions in the U.S nation, computing for 38% of total U.S. CO_2 emissions and 31% of total U.S greenhouse gas (GHG) emissions in 2012. The different type of fossil fuel needed to produce electricity will emit different quantity of CO_2. In order to generate a given quantity of electricity, burning coal will produce more CO_2 than natural gas and oil.

Methane (CH_4) emissions consequence from the metabolism of organic matter by microorganisms under anaerobic circumstances while the nitrous oxide (N_2O) emission take place as a by-product throughout the conversion of ammonium and organic nitrogen into nitrogen gas, through nitrification and denitrification process. These emissions mostly take place in the treatment process, and in the receiving environment after discharge from the wastewater treatment plant.

Sodium Hypochlorite (NaOCl) and Sodium Percarbonate are used for disinfection in wastewater treatment plant. Sodium Hypochlorite is a compound that can be efficiently applied for water purification and disinfection due to simple dosage as well as safe to transport and storage. However, Sodium Hypochlorite is a corrosive and dangerous substance. Safety measures should be taken to protect and save the workers and the environment. Sodium Hypochlorite as well as Sodium Percarbonate should not come in contact with air as it will cause disintegration process to occur.

The possible remedy that can be applied to reduce the impact and damage of wastewater treatment plant toward environment is to restrict the consumption of electricity in treatment plant. Restriction means to reduce the usage of fossil fuel to generate electricity and utilize the alternative renewable power source such as solar and biomass energy. Most of the new treatment plant already implement this kind of technology to generate electricity thus reducing the cost to operate the plant. The excess methane gas from sludge treatment plant can be further process to be converted into the electricity to power up the utilities plant. Thus, will also reduce the excessive emission of methane gas to the environment. Solar energy also can be one of the alternative source to generate electricity, provided with the suitability of the geographic and weather condition in that area.

Sewage sludge is one of the end product of municipal wastewater treatment plant. However, proper sludge management often abandoned in contrast with water-related parameters such as the leaving load and the degree of discharge of different wastewater compounds. Sludge is a potential threat and burden for the environment. Foaming sludge can be gone from the treatment process and may be even intentionally disposed of into watercourses discharge point. Wastewater sludge treatment is more than only dewatering, digestion, thickening, and disposal. It has significances for the whole wastewater treatment plant. A proper sludge management also need to be focused in order to reduce the environmental burden. For example sludge-originated biogas, it is potential to increase the energy production to over 100% of the power required in the plant. Energy production and energy efficiency are very essential issues. It is also promising to increase biogas production with the certain pre-treatment methods.

Chlorine is used for wastewater disinfection, for example hypochlorite salt. Chlorine reacts with water to produce hypochlorous acid (HOCl), which quickly dissociates to form the hypochlorite ion according to the following reaction:

$$HOCl \rightleftharpoons OCl^{-} + H^{+}$$

Effective chlorine disinfection depends on the accurate combination of pH, chlorine, contact time, concentration as well as the levels of ammonia and suspended solids. One disadvantage of chlorine disinfection is free and combined chlorine residues being toxic to aquatic organism as well as the surrounding environment. There is also possible for the formation of organo-chlorinated derivatives. These derivatives are specific concern, as they have a tendency to be relatively toxic, bio-accumulative and persistent. The alternative way to replace the chlorination for disinfection process, is by using UV disinfection and detention lagoons. The advantage of UV disinfection process is, it is rapid and does not add to the toxicity of the wastewater. There have been zero report on by-product produced from UV disinfection process that adversely impact on the receiving environment.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Global awareness on the importance of preserving our Mother Nature is truly crucial during this day. Continuously development of technologies had caused a trouble to the environment. The main objective of wastewater treatment is to reduce the environmental impacts from the wastewater. However, should be emphasized that such treatment in turn produces the adverse impact on the environment. Therefore, it is clearly important to conduct this life of cycle assessment to evaluate the environmental impact correlated with wastewater treatment plant. The outcomes of this study can be further applied in expand the strategies to minimize the adverse impact to the environment.

As a conclusion, this project has achieved its objectives which are to use ReCiPe method to conduct life cycle assessment (LCA) on wastewater treatment and to evaluate the environmental impact of the wastewater treatment plant. Wastewater treatment plant is a present technology facility to treat the sewage, industrial effluent and municipal waste to achieve minimum allowable discharge quality as per requirement by Department of Environmental (DOE). Thus, it is important to ensure that the wastewater treatment plant does not have any major effect on the environment which would lead to massive problems in the future.

In this project, the inventories data were designed based on literature review on wastewater treatment plant in Latin America. The treatment system was divided according to the balance of system (BOS) which is subsystem 1 is from preliminary and primary treatment, subsystem 2 is from secondary and tertiary treatment and subsystem 3 is from sludge treatment system. The assessment also involved the construction and equipment fabrication phases including the transportation for plant purposes. The inventories data were computed into SimaPro software based on yearly basis calculation.

This project’s outcomes would beneficial to the wastewater treatment industry as it evaluate the overall environmental impact resulted from the life cycle of wastewater treatment system. The government or private industry were highly recommended to review and analyze this outcomes prior to the treatment plant development project.

For future recommendations, the life cycle assessment of wastewater treatment plant can be applied in Malaysia prospect. As the best of our knowledge from the preliminary study, there has never been a research done for LCA of wastewater treatment plant in Malaysia. From the preliminary research, there is lack of inventory data for wastewater treatment plant in Malaysia. Thus, the researcher needs to do the thorough research from the real plant in order to collect the inventory data. The inventory data is a very data demanding and the most challenging stage as it requires a technical study on the nature of wastewater treatment system. Despite of the basic parameter such as BOD, COD and plant capacity, the construction and equipment fabrication phase also need to be considered as the life cycle assessment is a study from beginning toward the end of life process. The laboratory research required to be done as to evaluate the wastewater content in each and every treatment stage, influent and effluent. The background function such as electricity consumption and amount of raw chemical material used in plant operations also the important parameter need to be collected as well.

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