CONDUCTING LIFE CYCLE ASSESMENT (LCA) ON PRODUCTION PROCESS IN PT. X

FINAL PROJECT

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CONDUCTING LIFE CYCLE ASSESSMENT (LCA) ON PRODUCTION PROCESS IN PT. X

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ORIGINALITY STATEMENT

I certify that the research entitled "Conducting Life Cycle Assessment (LCA) on Production Process in PT. X" has not been submitted for any other degree.

I certify that to the best of my knowledge, this research I wrote does not contain any work parts of the other people's work, except those cited in quotations and bibliography, as scientific papers requirement. In addition, I certify that I understand the rule stated by the Ministry of Education and Culture of The Republic of Indonesia, subject to the provisions of *Peraturan Menteri Pendidikan Nasional Republik Indonesia Nomor 17 Tahun 2010 tentang Pencegahan dan Penanggulangan Plagiat di Perguruan Tinggi.*

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PREFACE

Praises to God for His blessings and guidance that led the author to finish this research, entitled “CONDUCTING LIFE CYCLE ASSESSMENT (LCA) ON PRODUCTION PROCESS IN PT. X”. This research specifically conducted as Final Project, one of the enquirement to achieve bachelor degree in University of Atma Jaya Yogyakarta, Faculty of Industrial Technology, International Industrial Engineering Department. During the working process of this research, the author received many helps from several parties. Therefore, in this occasion the author wants to give gratitude for several parties that have helped the author including:

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The author realizes that this research is far from perfect, therefore the author is open for constructive suggestions and advices regarding this research. However, the author hopes that this research will be useful for all of the readers.

Yogyakarta, December 16th,2020

Noel Kurnia Lahardo

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ABSTRACT

One of the greatest contributors of environmental damage in the world are manufacturers. Therefore, an assessment of environmental impacts caused by manufacturers is necessary, and included in ISO 14001: 2015. One of the requirements in ISO 14001: 2015 is Life Cycle Assessment (LCA). PT. X, a large printing company in Jawa Tengah located in a high population district area with a population density of 1,698 people/km^2 (BPS, 2018) in 2015, is concerned about the environmental health surrounds the company, especially for the human health aspect for the employees. In order to maintain the human health aspect in PT. X, an LCA on production process in PT. X is necessary to be conducted to identify which process harm the human health aspect. The LCA in this research conducted according to ISO 14040 LCA steps, including: goal and scope definition; inventory analysis; impact assessment; and interpretation. The goal and scope step in this research decided for the production process in PT. X, with time span of six months in 2019. The inventory analysis step in this research discovered the additional vapor emission outputs of Aminoethylethanolamine in plate printing process, Hexane in printing process, and Isopropanol in varnishing process. The impact assessment step in this research conducted using openLCA software, with GaBi 2018 database and ReCiPe Midpoint method. The interpretation step in this research concluded that the processes with significant environmental impacts regarding human health for production process in PT. X are printing process and varnishing process. To reduce the emission caused from those processes, this research suggested to add dilution ventilation in those processes. This research also suggests PT. X to substitutes the using of: Aminoethylethanolamine compound into turpentine oil; Isopropanol compound into hydrogen peroxide; and silicone liquid into phosphate esters.

CHAPTER 1

INTRODUCTION

1.1. Background

Environmental issues have been arising in the past several years, especially for environmental damage. Environmental damage is defined as the decrease of environmental quality through depletion of natural resources such as water, land, and air. The impact of environmental damage can harm the ecosystem, especially human beings. It may impact directly on human health and, indirectly, through the decrease of natural resources quality and extinction of animals and plants.

One of the greatest contributors of environmental damage in the world is factories, or, in industrial context, manufacturers. A manufacturer is a company or an organization that processes raw materials into products or finished goods. According to Oyinloye (2015), approximately 23-30% of environmental damages in the world are caused by factory's waste pollution, which includes water pollution, air pollution, and soil pollution which are dangerous for human beings. Therefore, the assessment of environmental impacts is necessary for factories in order to maintain the ecosystem including human beings who live around the factory.

The assessment on environmental impact for factory or manufacturer is already included in ISO 14001: 2015, which is an update from ISO 14001: 2004. ISO 14001 regulates the environmental management system of a company or manufacturer, and it is legitimate internationally. One of the updates in ISO 14001: 2015 is the inclusion of Life Cycle Assessment (LCA). It means that a manufacturer needs to conduct LCA and understand its interpretations in order to fulfill the requirement of ISO 14001: 2015.

In Indonesia, there is already a regulation about the standardization and compatibility valuation in Act No. 20 Year 2014. The standardization and compatibility valuation in the regulation regarding the protection of environment, can also be fulfilled through LCA. Therefore, manufacturers in Indonesia need to conduct LCA, to either get the ISO 14001: 2015 certification and fulfill Indonesian government's rule. Conducting LCA can also benefit the manufacturer itself, since it maintains the health of resources and human beings inside and around the manufacturer.

With LCA conducted, manufacturers can also reduce the production cost. This condition can be reached because the LCA will encourage sustainable product, which means a longer life product. Sustainable products tend to opt for recycled materials and energy, which tend to be cheaper. Besides, from LCA result, manufacturers can also detect the most efficient available alternatives for material and energy usage.

LCA is often compared to AMDAL, since AMDAL is also standardization of environmental impact tool for the manufacturers. AMDAL is mainly conducted to identify the valuation of impacts from production activity for the environment. The difference of AMDAL and LCA is that AMDAL is only a tool of valuation, meanwhile LCA is more of an analysis method. AMDAL is also focus on the local environment effects, rather than LCA that analyzes with a regional or global perspective. It can be concluded that LCA is more qualified as a national or regional standard compared to AMDAL. Also AMDAL is not qualified as the requirement of ISO 14001: 2015 certification.

Based on data from BPS (2017) in 2017 there are only 2,197 manufacturers certified with ISO 14001: 2015 in Indonesia. Meanwhile, in 2017 there are total of 33,577 manufacturers in Indonesia, with 11,000 large manufacturers. Large manufacturers have more than 100 employees and are obliged to maintain the environmental health. This obligation is based on Indonesian government’s rule in Act No. 32 Year 2014 about protection and management of living environment. With only 20% of the 11,000 large manufacturers already certified with ISO 14001: 2015, environmental health in Indonesia is pretty concerning.

Environmental health concern in Indonesia is increasingly crucial, especially for environment around manufacturers. There are human and other organisms that live near the manufacturers areas, and the employees and resources inside the manufacturers. Ironically there are many manufacturers located in high populated areas. This case happened with PT. X as a manufacturer of textbooks, leaflets, brochures located in a city in Jawa Tengah. PT. X located in a district with a population of 40,865 people (BPS, 2019), with a population density of 1,698 people/km^2 (BPS, 2018) in 2015.

PT. X as a large manufacturer is already certified with ISO 14001: 2015, but have been struggled to interpret and implement the LCA continuously. Meanwhile, the ISO 14001: 2015 certification requires continuous improvement, including LCA. The worst case this condition could lead is the removal of ISO 14001: 2015 certification from the manufacturer. Besides, PT. X is also aware of environmental health especially because it is located in high populated area. Moreover, some operators working in the production plant of PT. X confessed, that the smell of some chemical compounds used in the production process are irritating. PT. X realizes that maintaining the environmental health is as important as conducting the manufacturing itself. PT. X is also cares about the health of its employees, realizing that the employees are important assets for the company.

Therefore, this research is necessary to help PT. X, especially the HSE Department in continuously caring out the LCA and maintaining the environmental health surrounding PT. X especially for human health. This research also help PT. X to identify which process causes negative impacts for environmental health, and needs to be improved with emission reduction effort. This research is conducted particularly for the LCA step, which is one from nine steps required by ISO 14001: 2015. The result of this research is planned to be an identification of which process causes negative impacts for environmental health especially human health in PT. X, along with the proposal of emission reduction effort for PT. X.

Emission reduction effort is an act of changes or improvement in order to reduce the environmental impacts caused by a production process. In this research, the proposal of emission reduction will be conducted within production process of PT. X. The proposal of emission reduction effort will be taken from available studies regarding the environmental impacts from the result of LCA in PT. X.

1.2. Problem Formulation

The needs of PT. X to identify which processes that cause negative impacts for environmental health especially human health, in order to do the emission reduction effort leads to the needs of conducting LCA on production process in PT. X.

Problem formulation in this research can also be formed into questions that this research needs to answer. Questions that needs to be answered within this research are:

a. Does PT. X as a manufacturer that located in high population area, causes negative impacts for environmental health?
b. What processes cause the negative impacts for the surrounding environment of PT. X?
c. What kinds of negative impacts caused by production process in PT. X?
d. What are the emission reduction efforts that PT. X can implement in order to lower the cause of negative impacts for human health?

1.3. Objective

The objective of the research is to identify which processes cause negative impacts for environmental health especially for human health in PT. X, in order to do the emission reduction effort in PT. X.

1.4. Scope and Limitation

The scope and limitation for this research are:

a. The LCA in PT. X will be conducted for its production process with time span of 6 months in 2019;
b. LCA is conducted using OpenLCA software 1.9 version, with GaBi 2018 database and ReCiPe Midpoint impact assessment method;
c. Several production processes and inventory data are restricted for public;
d. Waste management process is ignored in the research;
e. PT. X does not allow any pictures taken during the observation.

CHAPTER 2

LITERATURE REVIEW & THEORETICAL BACKGROUND

2.1. Literature Review

There are some LCA researches that can be used as the reference for this research. Those studies have various cases of LCA, along with different software and methodology used. The different cases of LCA serve different purposes too.

An LCA to compare the environmental impacts and Cumulative Energy Demands (CED) between reading printed books and reading e-books from an Apple Air iPad was conducted by Naicker and Cohen (2016). The research conducted specifically in South Africa, with the functional unit of 21 books each for printed books and e-books in Apple Air iPad. The number of 21 printed books and e-books assumed to represents the amount of books needed to finish a four year commerce degree at the university in South Africa. The research also serves an investigation of the impacts from the Integrated Resource Plan (IRP) electricity mix, a change of electricity with including more nuclear and renewable energy in the mixture. The LCA in this research uses SimaPro v8.1 software, with ReCiPe Midpoint and CED impact assessment method. The result of comparative LCA in this research concluded that the potential impacts produced for 21 e-books from an Apple Air iPad were preferable compared to 21 printed books. The amount of energy used for 21 e-books from an Apple Air iPad (473 MJ) was also a lot lower compared to 21 printed books (1,525 MJ). The result also concluded that the using of IRP electricity mix decreases the environmental impacts and CED for both of 21 printed books and 21 e-books from an Apple Air iPad. The LCA conducted for 21 printed books in the research, can be used as an example for conducting LCA in PT. X. However, the LCA of 21 printed books in the research also includes the production of paper, which is not exists in production process of PT. X.

LCA to identify the environmental impacts of Mizone production process and waste management at PT Tirta Investama Klaten is conducted by Hamonangan *et al*. (2016). The research is conducted along with the recommendation for improvement in the production process and waste management of Mizone product, in order to minimize the environmental impacts. Hamonangan *et al*. stated this research is necessary for manufacturers, since the increasing concerns of negative environmental impacts produced by manufacturers including global temperature rise and sea level rise. Especially for PT Tirta Investama Klaten which is located near human beings population, Hamonangan *et al*. thought the need of LCA for the manufacturer getting crucial. LCA in this was research conducted according to ISO 14040: 1997 steps using SimaPro software with EDIP/UMIP 97 impact assessment method. The results of this research stated that Mizone production process and waste management potentially produce global warming, ozone layer depletion, acidification, eutrophication, photochemical oxidation, and land use environmental impacts. Therefore the manufacturer was recommended to do machine maintenance periodically, replacing the fuel from solar into bio solar, and replacing PET materials into carton. Replacing the fuel into bio solar can reduce CO_2 emission until 78.5% compared to solar fuel.

Normann and Maier-Speredelozzi (2016) conducted a research in order to design a more sustainable manufacturing. One way to assess sustainability is by using environmental impacts approach. Normann and Maier-Speredelozzi believed that customers nowadays are aware of environmental impacts, including environmental impacts caused by the product they bought. The challenge is to design a sustainable manufacture along with cost reduction. Therefore, Normann and Maier-Speredelozzi tried to demonstrate an overlap between sustainability and cost reduction with developing three manufacturing models, the first one being the current state model while the second and third being new alternative models. The sustainability assessment was conducted according to ISO 14040: 2006 steps using NXT Umberto software with ReCiPe midpoint impact assessment. The cost used aPriori CACE (Computer Aided Cost Estimating) software. The result can be concluded that model 2 has the most environmental impacts reduction of 5% compared to the current state model, along with cost benefit for the manufacturer. The changes in model 2 compared to the existing manufacturing state in the research are the substitution of mineral based metalworking fluid into coconut oil based fluid and the removal of painting process.

An LCA of chemical treated paper production using wood waste was conducted by M’hamdi *et al*. (2017). Chemically treated wood waste potentially produces environmental impacts, while it can, actually, be recycled. Conventional paper production using pulps is also analyzed in this research as a comparison for the chemical treated paper production using wood waste. LCA in this research is used as an assessment tool, to expand the system boundary of the chemical treated paper production using wood waste until the utilization on final product. The LCA was conducted using SimaPro software with IMPACT 2002 impact assessment method. The results of this research stated that conventional paper production using pulps has significant negative impacts especially for human health and ecosystem quality impact category compared to chemical treated paper production using wood waste. The negative effects produced from conventional paper production using pulps mainly are caused by the usage of black liquor, which contains multitude of mixed chemicals.

A research to identify environmental impacts of paper production in Iran using LCA was conducted by Rozana (2013). Pulps and paper production is one of the biggest in the world in spite of the environmental impacts caused by the production process, with 299,000,000 MT produced worldwide in 1997. Rozana also claimed that the demand of paper will increase by 2.1% until 2020, with the fastest demand growth in Eastern Europe, Asia except Japan, and South America. Therefore Rozana thought Iran as one of paper manufacturing nations in Asia needs to conduct LCA to maintain the environmental impacts caused by the paper production processes. LCA was conducted in this research according to ISO 14040 steps by using SimaPro software with CML2 Baseline impact category method. The results of this research concluded that electricity produces the lowest environmental impacts from all of impact categories except for global warming. Meanwhile fuel consumption produces the highest environmental impacts in abiotic depletion (85%) and global warming (25%) impact category. Chlorine consumption also produces the highest environmental impacts in ozone layer depletion impact category by 62%. The recommendations of this research to minimize the environmental impacts caused by paper production process in Iran are to replace the fuel into renewable energies such as nuclear power, and to replace Chlorine with a more environmental friendly material.

A comparative LCA was conducted by Unterreiner *et al*. (2016) to compare an ecological impact of recycling and reusing materials for three different battery technology. The three battery technologies are lead acid, lithium ion, and vanadium redox flow battery. The LCA in the research was conducted according to ISO 14040 and ISO 14044 steps by using NXT Umberto LCA software. Ecoinvent database and ReCiPe impact assessment method were also used. The results of this research concluded that the recycling and reusing material of lead acid battery has the most significant ecological impact, decreasing 49% of environmental impacts. The environmental impacts decreased by recycling lead acid battery including metal depletion and human toxicity impact category. Meanwhile the recycling of vanadium redox flow battery has the least significant ecological impact, only decreasing 16% of environmental impacts. However the recycling and reusing material for vanadium redox flow battery has not been applied, because it potentially requires high cost. Therefore Unterreiner *et al*. hoped that there will be research to develop the recycling and reusing materials for vanadium redox flow battery.

Meanwhile LCA for household hazardous waste was conducted by Fikri *et al*. (2014) in Semarang, Jawa Tengah. The research was conducted to produce the most effective and efficient model of controlling household hazardous wastes, by considering the environmental impacts caused by the household hazardous wastes. Fikri *et al*. believed even though the greatest resources of hazardous waste are manufacturers, in fact households also produce hazardous waste. The environmental impact in this research focused in global warming potential (GWP), with the indicator of greenhouse gas (GHG) emission. The research was conducted with Slovin formula to generate a number of samples, and LCA according to ISO 14040: 2006 steps associated with GWP by using IPCC 2007 impact assessment. Six different scenarios were generated. The result of this research stated that scenario 3 with metal recycling (cans) waste management has the highest GWP contribution, even higher than the metal recycling (can) industry. Meanwhile the least GWP contribution was from scenario 2 with the segregation and integrated waste processing facility along with the use of electrical energy from fuel gas.

An LCA to evaluate, for the first time, environmental impacts of renewable electricity in Turkey was conducted by Atilgan and Azapagic (2015). The research was to explore the environmental sustainability of renewable electricity resource in Turkey to provide a baseline for the future planning. Atilgan and Azapagic considered 305 electricity generation plants utilizing hydro, wind, and geothermal power, including the large and small reservoirs. The LCA in this research is in accordance with the ISO 14040 and ISO 14044 steps using GaBi software with CML 2001 impact assessment method. As the LCA in this research was conducted for energy, the functional unit used environmental impacts per kWh electricity generated. The results of this research concluded that onshore wind plants is the worst option in term of per kWh electricity generated, with 88% of GWP impact category contribution. Besides, large reservoir plants are more sustainable compared to small reservoir plants especially in photochemical oxidants creation potential (PCOP) impact category which is 45% lower than small reservoir plants. Meanwhile geothermal plants are the best option for 6 impact categories including eutrophication, ozone layer depletion, human toxicity, and all of ecotoxicity impact categories. Atilgan and Azapagic claimed in the research that even if the renewable electricity causes some environmental impacts, but it is still lower compared to environmental impacts caused by fossil fuels electricity.

A research to evaluate the potential environmental impacts of natural direct cotton dyeing process using LCA was conducted by Linhares and de Amorim (2017). The natural direct dyeing material on cotton in the research was obtained from Acacia Dealbata tree bark, an invasive species especially in mediterranean countries. Linhares and de Amorim claimed that one of the solutions for the invasive species is using the extraction from Acacia Dealbata's bark as a textile dye. The research was also conducted to emphasize on the ecological benefits of using extraction from Acacia Dealbata's bark as a textile dye. LCA conducted in this research is based on ISO 14040 steps using GaBi software with ReCiPe impact assessment method. The research using natural dyes conducted for cotton dyeing process. The results of this research concluded that dyeing 1kg of cotton with direct natural dyes process only produces 0.7kg of CO_2eq in climate change impact category. It is much lower compared to synthetic colour dyes process cotton which produces 12.4kg of CO_2eq. However, the result of direct natural dyes process has a medium colour, compared to the synthetic colour dyes process.

2.2. Theoretical Background

2.2.1. Definition of LCA

To conduct LCA, the definition of LCA itself should be clear. There are some different definitions of LCA according to some references:

a. UKEssays (2018) defines that LCA is a way of linking inputs and outputs of a product for the environment, and provides possible solutions to lower the environmental impacts of the product.

b. Curran *et al.* (2008) defines that LCA is an environmental accounting and management approach that considers all the aspects of resource usage and its environmental impacts associated with an industrial system from cradle to grave. It is an environment interaction that covers a range of activities started from the extraction of raw materials and productions until the distribution of energy. Curran also stated that LCA is a tool to help the decision makers compare various environmental impacts in order to choose the best alternative of actions or decisions.

c. LCA is a method for calculating the environmental impacts of a product or service as stated by Jonker and Harmsen (2012). The calculation is based on a functional unit, can be a unit of material, a unit of energy, or a unit of service. The basic of LCA is done for the entire phases including pre-manufacture, manufacture, also the use and disposal of the product.

d. LCA is defined as a framework for assessing the environmental impacts of product systems and decisions as stated by Cowie *et al*. (2019). The result of LCA is expressed in a functional unit. Because of the flexibility of LCA framework, it is suitable for small and large scale of systems and for micro or macro decision making.

e. Caro and Fath (2019) defines LCA as a very popular analysis for reporting potential environmental loads and resources consumed in each step of a product or service supply chain. LCA has a high accuracy and can provide the responses for any alternative actions. Those responses are useful for decision or policy makers to understand the environmental impacts caused by each decision.

2.2.2. Steps of LCA

To conduct the LCA, there are several steps to take based on ISO 14040 and the explanation for each step according to Muralikrishna and Manickam (2017) are as follow:

a. Goal and Scope Definition

This step aims to define how big a part of product life cycle will be considered in assessment. The criteria serve for comparison system and specific time range are also described in this step.

The important thing in this step is to simplify the models in LCA, where the most important choices are described. The reason for conducting LCA is also described in this step, along with clear definition of life cycle of the product and the system boundaries.

b. Inventory Analysis

This step gives a description of material and energy flows within the production system, such as consumed raw material and energy data along with the emissions. Input and output data of production system is also required for this step.

c. Impact Assessment

This step gives details of indicator results from all of impact categories. The importance of every impact category is assessed by normalization and also by weighting score.

This step also classifies the environmental impacts, and then evaluate them from what is the most important one. The desired level of integration results is also important to describe in this step.

d. Interpretation

This step includes critical review, determination of data sensitivity, and the presentation result. The conclusion of LCA will be described in this step. With the conclusion and results, improvement and decision can also be recommendation.

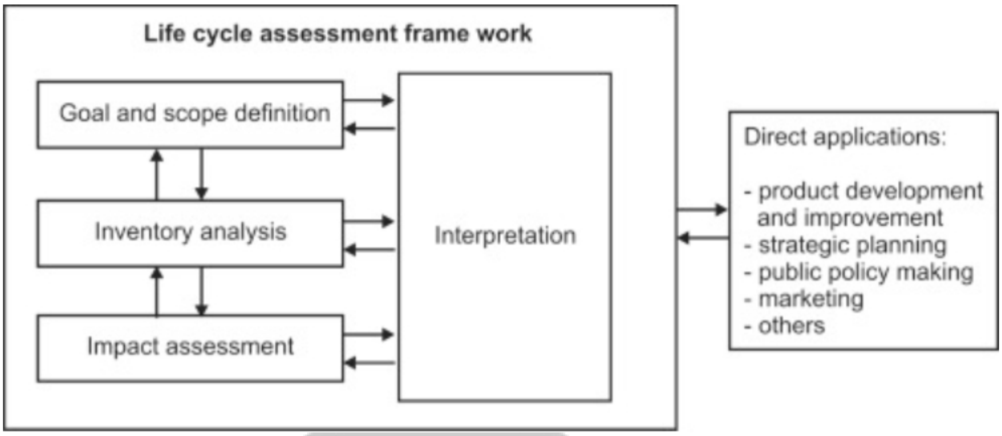

Figure 2.1. Steps of LCA According to ISO 14040

2.2.3. System Boundary of LCA

a. Definition of System Boundary

System boundary is a simplified flow of energies and materials used in the production activity. The simplification of flow of energies and materials is conducted by excluding negligible activities that have no potential impact of emission or identical activities as stated by Tillman *et al.* (1993).

According to Tillman *et al.* (1993) System boundary has to be specified in many dimensions as shown below:

i. Boundaries between the technological system and nature

LCA begins with the acquisition of raw-material or non-renewable resources. The process to acquire the raw materials to be ready to process should be included in the system boundary along with the treatment on its land or forest. For flowing resources, the transportation and energies used such as gasoline or solar should be included to identify the potential emission.

ii. Geographical area

LCA must somehow be geographically restricted, because the sensitivity of environment to pollutants are different from one regions to another. It is also possible that a waste in a region is used as a raw material in another region.

iii. Time horizon

LCA conducted based on the concerns about present and future environmental impacts caused by present day production activity. However, some of the materials and energies used in the production activity often have longer environmental impacts. Therefore a restricted time span during which a survey can be conducted should be decided. The lifetime of materials and product should be considered in deciding the time span.

iv. Capital goods

LCA may give the information whether it is beneficial or not to invest in a new equipment with less environmental impact. To get the information, the comparison of LCA between the existing equipment and new equipment is needed.

v. Boundaries between the life cycle of the product studied and related life cycles

Most industries are related to each other, including its activities. Therefore boundaries should be set to specify the flow of energies and materials. There are 3 principal methods to define the contents of system, ranging from the smaller to the larger:

a) Process Tree (PT)

In the PT method, only the processes and transportations that directly involved to the production and disposal of the materials that are included in the system. The flows go upstream until reaching the acquisition of raw materials or resources. Only the mainstream goes downstream until the elementary flows. Only single process function is made in this method.

b) Technological Whole System (TWS)

In the TWS method, all processes and transports affected by the choices of compared alternatives of systems are included. This method is suitable for processes with multiple energies and materials. However, this method ignores the economic and social aspects of the processes.

c) Socio-economic Whole System (SWS)

In the SWS method, processes and transports included are the same with the TWS method with the consideration of the social and economic aspects. However, the goal is still restricted to environmental impact caused by the production activity.

b. Application of System Boundary

There are several types of system boundary applications according to Tillman *et al.* (1993):

i. Multiple functions

Multiple functions mean that there are multiple different products produced in a single process. The visualization of multiple functions applications in system boundary shown in Figure 2.2:

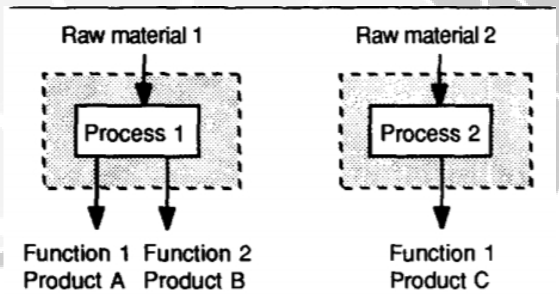

Figure 2.2. Application of Multiple Function in PT Method

In Figure 2.2, process 1 shows the application of multiple functions in system boundary, where product A has a by-product in the form of product B. Process 2 only produces product C, which indicates the application of process tree (PT) method. Whereas product B as a by-product of product A can also serve as energy or useful waste form, such as heat.

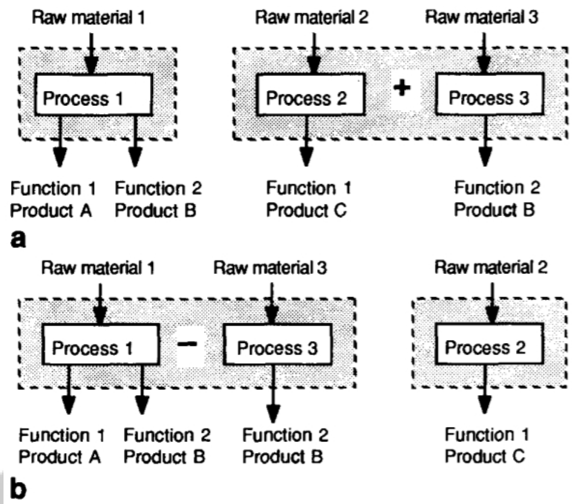

Figure 2.3. Application of Multiple Function in TWS Method

The upper side of Figure 2.3. shows the application of multiple functions in TWS method, where process 1 produces product A and product B. In the separate boundary system, process 2 produces product C and process 3 produces product B. Process 3 can be added into the same boundary system as process 1 because it produces the same product, product B. The addition can be seen in the lower side of Figure 2.3.

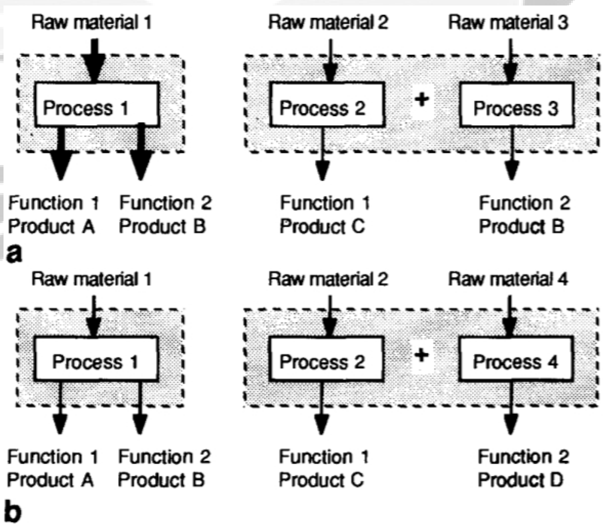

Figure 2.4. Application of Multiple Functions in SWS Method

Figure 2.4 shown the application of multiple functions in SWS method, where the arrow in process 1 is thickened. The thickened arrow means that in process 1 has a big social and economic impact. In figure 2.4 can also be seen that process 3 has a same product output as process 1, so process 3 can be excluded and replaced by process 4. The replacement of process 3 into process 4 can be seen in the lower side of Figure 2.4.

ii. Cascade Recycling

Cascade recycling means that a product produced in a process is being recycled or used again in another process, with a quality reduction. Cascade recycling application in LCA is done with considering whether the recycling or reusing activity is beneficial for the environmental impact.

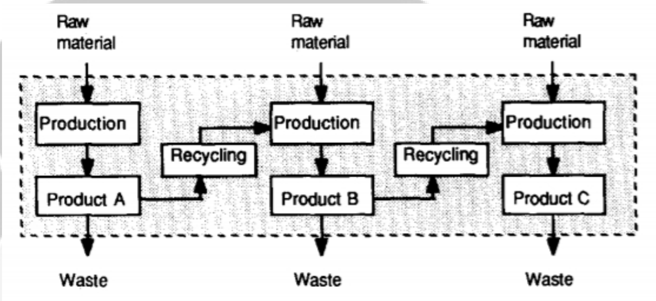

Figure 2.5. Application of Cascade Recycling in System Boundary

Figure 2.5 shows that product A is recycled to produce product B, and product B is recycled to produce product C. It shown that the system boundary apply Cascade recycling.

Cascade recycling can also be applied with external material pool. External material pool can be a supplier for the raw material, or a waste shelter within the company.

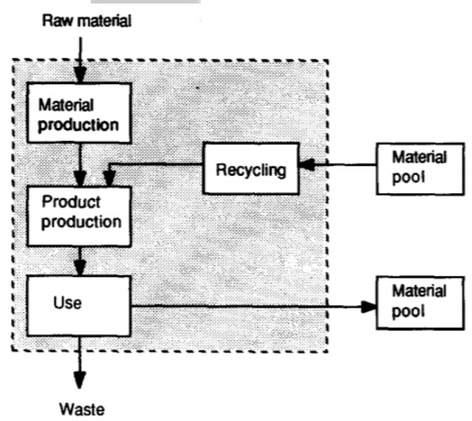

Figure 2.6. Application of Cascade Recycling With External Material Pool

From the figure 2.6, it can be seen that materials being recycled or reused come from external material pool. It means that the recycling or reusing activity is not using the product from inside system boundary.

2.2.4. LCIA Methods In OpenLCA Software

LCIA or impact assessment is a step in LCA after the goal & scope definition and inventory analysis steps have been taken. In LCIA step, the environmental impact categories are calculated based on its importance. There are many methods with different approaches and impact categories included in Nexus website generated by openLCA software. Nexus website currently provides over 30,000 data sets including methods and databases for LCIA methods in openLCA software.

Some of LCIA methods provided by openLCA software can be downloaded for free according to Acero *et al.* (2015):

a. CML

CML method is divided into baseline and non-baseline method, with the baseline method being the most common one. CML method was developed by the University of Leiden in Netherlands in 2001. This method is broadly used to identify environmental impacts in industries, since its impact categories are one of the most common. The impact categories of CML baseline method can be seen in figure 2.7:

Method: **CML (baseline)**	
Impact category group	**Name of the impact category in the method**
Acidification	Acidification potential - average Europe
Climate change	Climate change - GWP100
Depletion of abiotic resources	Depletion of abiotic resources - elements, ultimate reserves
	Depletion of abiotic resources - fossil fuels
Ecotoxicity	Freshwater aquatic ecotoxicity - FAETP inf
	Marine aquatic ecotoxicity - MAETP inf
	Terrestrial ecotoxicity - TETP inf
Eutrophication	Eutrophication - generic
Human toxicity	Human toxicity - HTP inf
Ozone layer depletion	Ozone layer depletion - ODP steady state
Photochemical oxidation	Photochemical oxidation - high Nox

Figure 2.7. Impact Categories of CML Baseline Method

b. Cumulative Energy Demand (CED)

CED method in openLCA was developed based on the method published by the ecoinvent. The objective of this method is to calculate the primary energy needs throughout a life cycle of a product. The calculation of primary energy in this method includes direct and indirect uses of energy, but excludes waste reutilization for energy purpose. Impact categories in CED method can be seen in figure 2.8:

Method: **Cumulative Energy Demand (CED)**		
Impact category group	**Name of the impact category in the method**	**Reference unit**
Non-renewable resources	Fossil	MJ
	Nuclear	MJ
	Primary forest	MJ
Renewable resources	Biomass	MJ
	Geothermal	MJ
	Solar	MJ
	Wind	MJ
	Water	MJ

Figure 2.8. Impact Categories of CED Method

c. Eco-indicator 99

Eco-indicator 99 is possibly the most used LCIA method in openLCA. This method allows a single score expression on environmental impact. There are three types of damage in this method: human health, ecosystem quality, and resources. Because the objective of this method is to compare between products, the values resulted from this method are mostly just a comparison value. In this method there are three different cultural perspectives: Hierarchy (H), Individualist (I), and Egalitarian (E). Impact categories in Eco-indicator 99 method can be seen in figure 2.9:

Method: **Eco-indicator 99 (E), (H) & (I)**		
Midpoint/endpoint	**Impact category group**	**Name of the impact category in the method**
Midpoint	Ecotoxicity	Ecosystem Quality - Land conversion (PDF·m^2)
	Ecotoxicity	Ecosystem Quality - Land conversion (PDF·m^2·year)
	Ecotoxicity	Ecosystems Quality - Acidification and Eutrophication
	Ecotoxicity	Ecosystems Quality - Ecotoxicity
	Human toxicity	Human Health - Carcinogenics
	Human toxicity	Human Health - Climate change
	Human toxicity	Human health - Ionising radiation
	Human toxicity	Human health - Ozone layer depletion
	Human toxicity	Human Health - Respiratory effects caused by inorganic substances
	Human toxicity	Human Health - Respiratory effects caused by organic substances
	Depletion of abiotic	Resources - fossil fuels
	Depletion of abiotic	Resources - minerals
Endpoint	Depletion of abiotic resources	Resources-total
	Human toxicity	Human Health-total
	Ecotoxicity	Ecosystems-total

Figure 2.9. Impact Categories of Eco-indicator 99 Method (E), (H) & (I)

d. ReCiPe

The objective of this method is to combine CML and Eco-indicator 99 method with an updated version. There are 2 levels of indicator in this method: midpoint indicators and endpoint indicators with damage to human health, damage to ecosystem, and damage to resource availability. Impact categories of ReCiPe endpoint method can be seen in figure 2.10 and 2.11:

Method: **ReCiPe endpoint (E, H & I)**

Impact category group	Name of the impact category in the method	E	H	I
Acidification	Terrestrial acidification	TAPinf EQ-E	TAP100 EQ-H	TAP20 EQ-I
Climate change	Climate change	GWPinf HH-E GWPinf EQ-E	GWP100 HH-H GWP100 EQ-H	GWP20 HH-I GWP20 EQ-I
Depletion of abiotic resources	Metal depletion	MDPinf RD-E	MDP100 RD-H	MDP20 RD-I
	Fossil depletion	FDPinf RD-E	FDP100 RD-H	FDP20 RD-I
Ecotoxicity	Freshwater ecotoxicity	FETPinf EQ-E	FETP100 EQ-H	FETP20 EQ-I
	Marine ecotoxicity	METPinf EQ-E	METP100 EQ-H	METP20 EQ-I
	Terrestrial ecotoxicity	TETPinf EQ-E	TETP100 EQ-H	TETP20 EQ-I
Eutrophication	Freshwater	FEPinf EQ-E	FEP100 EQ-H	FEP20 EQ-I
Human toxicity	Human toxicity	HTPinf HH-E	HTP100 HH-H	HTP20 HH-I
Ionising radiation	Ionising radiation	IRPinf HH-E	IRP100 HH-H	IRP20 HH-I
Land use	Agricultural land occupation	ALOPinf EQ-E	ALOP100 EQ-H	ALOP20 EQ-I

Figure 2.10. Impact Categories of ReCiPe Endpoint Method (E), (H) & (I)

Method: **ReCiPe endpoint (E, H & I)**

Impact category group	Name of the impact category in the method	E	H	I
	Urban land occupation	ULOPinf EQ-E	ULOP100 EQ-H	ULOP20 EQ-I
	Natural land transformation	LTPinf EQ-E	LTP100 EQ-H	LTP20 EQ-I
Ozone layer depletion	Ozone depletion	ODPinf HH-E	ODP100 HH-H	ODP20 HH-I
Particulate matter	Particulate matter formation	PMFPinf HH-E	PMFP100 HH-H	PMFP20 HH-I
Photochemical oxidation	Photochemical oxidant formation	POFPinf HH-E	POFP100 HH-H	POFP20 HH-I

Figure 2.11. Impact Categories of ReCiPe Endpoint Method (E), (H) & (I)

From figure 2.10 and 2.11, HH means human health, EQ means ecosystem, and RD means resources. For the impact categories of ReCiPe midpoint method can be seen in figure 2.12:

Method: **ReCiPe midpoint (E, H & I)**				
Impact category group	**Name of the impact category in the method**	**E**	**H**	**I**
Acidification	Terrestrial acidification	TAP500-E	TAP100-H	TAP20-I
Climate change	Climate Change	GWP500-E	GWP100-H	GWP20-I
Depletion of abiotic resources	Fossil depletion	FDPinf-E	FDP100-H	FDP20-I
	Metal depletion	MDPinf-E	MDP100-H	MDP20-I
	Water depletion	WDPinf-E	WDP100-H	WDP20-I
Ecotoxicity	Freshwater ecotoxicity	FETPinf-E	FETP100-H	FETP20-I
	Marine ecotoxicity	METPinf-E	METP100-H	METP20-I
	Terrestrial ecotoxicity	TETPinf-E	TETP100-H	TETP20-I
Eutrophication	Freshwater eutrophication	FEPinf-E	FEP100-H	FEP20-I
	Marine eutrophication	MEPinf-E	MEP100-H	MEP20-I
Human toxicity	Human toxicity	HTPinf-E	HTP100-H	HTP20-I
Ionising Radiation	Ionising radiation	IRPinf-E	IRP100-H	IRP20-I
Land use	Agricultural land occupation	ALOPinf-E LOP-E	ALOP100-H LOP-H	ALOP20-I LOP-I
	Natural land transformation	LTPinf-E LTP-E	LTP100-H LTP-H	LTP20-I LTP-I
	Urban land occupation	ULOPinf-E	ULOP100-H	ULOP20-I
Ozone layer depletion	Ozone depletion	ODPinf-E M2E-E	ODP100-H M2E-H	ODP20-I M2E-I
Particulate matter	Particulate matter formation	PMFPinf-E	PMFP100-H	PMFP20-I
Photochemical oxidation	Photochemical oxidant formation	POFPinf-E	POFP100-H	POFP20-I

Figure 2.12. Impact Categories of ReCiPe Midpoint Method (E), (H) & (I)

2.2.5. Avogadro's Hypothesis

Avogadro's Hypothesis is a basis to determine the volume or number of molecules in the gas compound. Avogadro's Hypothesis states that equal volume of all gas compounds contain the same number of molecules when the gases are at the same temperature and the same pressure (Held, 2017). According to Avogadro's Hypothesis, a mole of any gases in STP condition (pressure at 1 atm, and temperature of 25°C = 298°K) has a volume of 22.4 Liters (Bama and Panangan, 2019). From this statement, can be concluded the correlation of mole, volume, and constant volume of gas in STP condition as equation 2.1:

$$\frac{V}{n} = k \qquad (2.1)$$

Explanation:

V : Volume (*L*)

n : Amount of mole (*mole*)

k : Constant volume of gas in STP condition (22.4 *L*)

This equation will be used for LCA in this research to conduct the emission analysis. The emission analysis conducted to get the estimated amount of compound in the gas emission in grams unit. The emission analysis also needs the mass value data of compound contains in the gas emission. Therefore, an equation from Ediati *et al.* (2008) is used.

$$Gram = mole.Mr \qquad (2.2)$$

Mr is a relative molecule value of the compound, can be calculated based on the molecular formula of the compound (for example Oxygen is O_2). The unit of Mr is g/mole. The data of relative molecule (*Mr*) was obtained from PubChem website.

CHAPTER 6

CONCLUSION & RECOMMENDATION

6.1. Conclusion

The conclusion of LCA in PT. X :

a. Process with significant contribution for the environmental impacts regarding human health in production process of PT. X are printing process and varnishing process.

b. The environmental impacts regarding human health caused by printing process and varnishing process originated from the compounds used in each process including Hexane and Isopropanol.

c. Environmental impacts regarding human health caused by production process of PT. X are human toxicity cancer, human toxicity non-cancer, photochemical ozone formation ecosystems, and photochemical ozone formation for human health.

d. Improvement or change in the printing process and varnishing process is necessary with the addition of dilution ventilation for each process and substituting the initial compounds with alternative compounds.

6.2. Recommendation

The recommendation for PT. X based on the result of LCA conducted :

a. Considering to apply dilution ventilation especially for printing process in printing division and varnishing process in finishing division as an emission reduction effort for PT. X.

b. Considering to substitute the use of Naphtha Solvent compound in printing process into Turpentine oil and substitute the use of IPA liquid in varnishing process into Hydrogen Peroxide.

c. Considering to substitute the use of Silicone liquid in binding process into phosphate monoester liquid, as an effort to maintain the resource availability of metal.

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