CHAPTER II

LITERATURE REVIEW

2. 1 Inductive Study

The environmental impact problem has been widely addressed by many researchers, especially those who put attention on life cycle assessment as one method commonly used in sustainability manufacturing. The inductive study below is from similar research of previous study.

Tabatabaie and Murthy (2016) presented a study about developing cradle to farm gate life cycle inventory and assessed the environmental impacts of strawberry production in four major strawberry producing states of the United States. The process was supported by using OpenLCA software, since this software able to examine the LCA for strawberry production. Then the data for California and North Carolina strawberry production were collected in collaboration with agricultural economists from those states using the "LCA Extended Enterprise Budget" Excel sheet (version 4.11). As the result, Global warming potential for California, Florida, North Carolina and Oregon strawberry production was estimated to be 1.75, 2.50, 5.48 and 2.21 kg CO2-eq per 1 kg of strawberry, respectively. From this paper can be concluded that the difference between LCA results was due to variation in yield and management practices which depend on geographic location.

Bhatt et al., (2019) performed a comparative life cycle assessment (LCA) of a low-impact-development (LID) parking lot test site to quantify the environmental costs of the manufacturing, and decommissioning of three bioretention cells and three permeable pavement systems (PPS) located in Ontario. The LCA in here was simulated to know and recognize the impacts on ten midpoint categories using a functional unit of "1m2 of impervious area treated". Cradle-to-grave was used as the system boundaries in this research. While, in creating the database for life cycle inventory is utilized using Ecoinvent v3 during the life cycle of the LIDs. The materials and energy used as the main concern generating the database. Then, for the impact assessment method, adopted TRACI 2.1. The author revealed that The cradle-to-grave impacts comparison between the bioretention and PPS indicates that the bioretention have lower impacts compared to the PPS on a basis of the "impervious area treated".

Widodo (2013) presented a research in applying of eco-efficiency in supply chain and production cluster at SMEs that produced Batik in Surakarta. Life cycle assessment and optimizing using the eco-efficiency approach method that was used. As a result, The Batik Laweyan cluster that has agreed to the concept of eco-efficiency through savings, product management, and good governance, is able to create an environmentally friendly industrial area and have economic power.

Göktepe et al., (2014) showed a study to protect and manage regions of natural and cultural resources by adopting the Strategic Environmental Management Plan (SEMP). This paper objective was analyzing the Salt Lake's unique environmental conditions and protect its biological endogenous factor that may arise in the future. In this paper, it is also developed creative and innovative approaches to use and to protect existing stocks by establishing a major paradigm to carry these approaches into future. At a result of the analysis, there were determined six ideal goals for Salt Lake and towards these ideal goals, Strategic Operational Environmental Management Model was created for Salt Lake.

Muhamad et al., (2013) presented a research about life cycle assessment of an oil palm seedling in Malaysia. The SimaPro (PRé Consultants, Netherlands) software was used for the study, and the life cycle impact assessment (LCIA) was carried out using the Ecoindicator 99 methodology. The LCA study is a gate-to-gate system boundary beginning with the germinated seed up to the planting and management of the nursery and, finally, the transport of the seedling to the specified field in the plantation. As result, the major factor that contributed to the environmental load was fossil fuel, which came from the two polybags used to raise the seedling. The impact of the polybags can be mitigated through the use of environmentally friendly biodegradable pots or bags.

Heikkurinen et al., (2019) presented a study about Business for sustainable change by extending eco-efficiency and eco-sufficiency strategies to consumers. These two methods are calling for businesses to take action regarding the prevailing unsustainable development. This paper aimed to examine how firm operating on the micro-level that meet to sustainability on the macro-level. The approach of eco-efficiency here was extended in business strategy that both increase the quality production and decrease the amount of the production, that was called as eco-sufficiency. As a result, the potential for sustainable change was not rooted in a single actor or mechanism but relied on differentset of catalyst for both eco-efficiency and eco-sufficiency, as well as influence customers to consumer better and less.

Ozturk and Dincer (2019) presented a study about comparative LCA for evaluation of environmental impacts of different fuels to generate electricity through combined cycle. In this paper, the methods considered in this study include CML, 2001 and ReCipe Endpoint. The results of the present LCA study for both methods show that the hydrogen is the best fuel option according to the environmental impacts. The impact categories obtained from CML 2001 are the depletion of abiotic resources, eutrophication, global warming, marine sediment, and aquatic ecotoxicity, freshwater aquatic ecotoxicity and the competition of land. Furthermore, the human health, ecosystems and resource availability are investigated with the ReCiPe Endpoint method. The greenhouse gas emissions per kWh electricity generation are 0.19 kg CO2 eq for solar, 1.21 kg CO2 eq for lignite, 0.53 kg CO2 eq for natural gas, 1.11 kg CO2 eq for oil and 0.04 kg CO2 eq for hydrogen according to the CML 2001 method.

Xie and Liu (2013) presented a study in evaluating the eco-efficiency of steel enterprises based on center-point triangular whitenization weight function. These methods also involve the AHP (Analytical Hierarchy Process) and also grey evaluation. There are two layers build, contain four categories (i.e. economic efficiency, resource and energy efficiency, ecological environmental efficiency, and circular economy) and second layer has 14 indexes. This paper showed the weighting process of each index then conducting grey comprehensive evaluation model based on center-point triangle whitenization weight function. The AHP analysis showed that resources and energy efficiency and circular economy have high importance, followed by economic efficiency and ecological environmental efficiency. The results showed the consistency with the real situation.

Charmondusit et al., (2013) conducted a research about quantitative measurement for SME in wooden toy industry. This research presented the significant indicator of eco-efficiency for quantitative measurement of the wooden toy industry. The key indicators include as economical aspect, environmental and social. This study contributed to environmental improvement in resource also the process efficiency by considering the net sales and gross marginal. It also beneficial for the SMEs in Thailand as the eco-efficiency evaluation that sticks to policy and strategic development.

Chen and Delmas (2012) presented a research in measuring the eco-inefficiency by using combination of two models which is Monte Carlo experiment and frontier model. This research has purpose to evaluate productive efficiency in the presence of undesirable outputs such as greenhouse gas emissions or toxic emission. At first, the frontier approach will build a model to score for each firm and improvements in output necessary to attain eco-efficiency. Then, through Monte Carlo experiment, provide a more a more reliable measurement of corporate eco-efficiency.

Buonocore et al., (2019) revealed a new method in terms of energy flows in marine ecosystem using emergy and eco-exergy. These methods are recognized as methods unfolding the role of matter and energy flows in the functioning of ecological systems. In this paper, the emergy and eco-exergy methods were used to account for the natural capital value of two Mediterranean Marine Protected Areas (MPAs) located in Southern Italy. In particular, the assessment focused on four main habitats. The emergy method allowed the assessment of natural capital in terms of direct and indirect solar energy flows invested for its generation, while the eco-exergy method accounted for the chemical energy stored in organic matter and the genetic information embodied in biomass stocks. The integration between emergy and eco-exergy methods resulted in a useful approach to account for different nature values based on a biophysical perspective.

Zheng et al., (2019) conducted a research on pavement maintenance alternative in which modelling using LCSA (Life-cycle sustainability assessment). This method that integrated life-cycle cost analysis (CLCA), environmental life-cycle assessment (E-LCA), and social life-cycle assessment (S-LCA). When the goal and scope were defined at the very first step, then pavement using LCSA were measured in the modelling process where the foreground project and background inventory data were collected. a multi-criteria decision-making model was applied to unify the three sustainability dimensions and select the appropriated sustainable pavement alternative. Finally, the results were discussed and highlighted in interpretation step, and a sensitivity analysis on weights was carried out.

Windrianto et al., (2016) presented a research in measuring the eco-efficiency level using LCA method to attain efficient production and environmental friendly. This research was observed in Batik Kuncoro Bantul, Indonesia. LCA in here was used to identify by applying proposed environmental improvement. Then after conducted interpretation, the method of EER (Eco-efficiency Ratio) was applied to know the sustainable level of a certain product within its entire life cycle. As the result from this research, the EER value for Batik Kuncoro was determined as 56% and the alternative substitute as 60%, it can be seen that the entire process has achieved affordable and sustainable.

Rifa'atussa'adah and Prabawani (2017) conducted a research in analyzing the eco-efficiency level in SME in Batik Tulis Bakaran Indonesia. In this method, the researcher also used the life-cycle costing and resulting in calculation of minimum NPO (non-product output). The object that will be assessed was involve the production only, so they adopted cradle-to-gate approach. The result showed that, alternative for substitute the raw material of production should be passing the proper and precise measurement, in order to avoid greater number of non-product output because much energy and material was wasted.

Harjanto et al., (2012) conducted a research at a cement manufacturer in Cilacap Indonesia (PT. Holcim) about the comparison of coal fuels and biomass. This research aimed to evaluate the effects of biomass utilization to environment using the LCA method. The system boundaries used cradle-to-gate approach to evaluate four scenarios of different fuel combinations. The functional unit to be measured was 1000kg cement production. The main raw material to process the cement only limestone and clay, other materials were complementary only. Then for each of the process will be compared with 4 different scenarios. The impact 2002+ will be used to analyze the impact assessment and divided into 3 analysis; characterization impact assessment, damage impact assessment and single score impact assessment. As the result, the development of biomass miscanthus giganteus as a coal substitution material needs to be done because miscanthus has the potential as a special plant for non-food fuel, so prices will tend to be stable.

Mahastuti (2017) presented a study in measuring the eco-efficiency level in SME of tofu manufacturer in Sukoharjo, Central Java, Indonesia in various production capacity whose own their own IPAL or installation of waste-water treatment. The research conducted with some methods; laboratory testing of waste produced from entire production process and comparison of EEI (eco-efficiency index), EER (eco-efficiency rate) and Eco Indicator 99 (H) with gate-to-gate system boundary approach. Eco Indicator 99 (H) will be used to categorize the production process and the supporting tools of Simapro v8.3 was carried out. As the result, the value of the Eco Efficiency Index (EEI) showed the first SME of 0.1528 and the second one of 0.0278, which means that the two SMEs were financially affordable but not environmentally friendly (unsustainable). Table 2.1 shows the summary of comparison among the previous studies related to system boundary and mehod used.

Table 2.1 Inductive study summary

Author	System Boundary's Approach			Method													
	Cradle-to-Grave	Cradle-to-Gate	Gate-to-Gate	LCA	LID	SEMP	Eco-eff	Eco-suff	ReCipe	AHP	Grey Ev.	LCSA	Monte C	EER	Eco-ind	Eco-exergy	Emergy
Tabatabaie and Murthy (2016)		√		•													
Bhatt et al., (2019)	√			•	•												
Widodo (2013)		√		•			•										
Göktepe et al., (2014)				•		•											
Muhamad et al., (2013)			√	•													
Heikkurinen et al., (2019)				•			•	•									
Ozturk and Dincer (2019)	√			•					•								
Xie and Liu (2013)	√			•			•			•	•						
Charmondusit et al., (2013)	√			•			•					•					
Chen and Delmas (2012)				•			•						•				
Buonocore et al., (2019)		√		•												•	•
Zheng et al., (2019)	√			•								•					
Windrianto et al., (2016)		√		•										•			
Rifa’atussa’adah and Prabawani (2017)			√	•										•			

Author	System Boundary's Approach			Method													
	Cradle-to-Grave	Cradle-to-Gate	Gate-to-Gate	LC A	LI D	SE MP	Eco-eff	Eco-suff	ReC ipe	A H P	Grey Ev.	LC SA	Mon teC	E E R	Eco-ind	Eco-exergy	Eme rgy
Harjanto et al., (2012)		√		•													
Mahastuti (2017)			√	•										•	•		
This research (2019)	√			•			•							•			

LCA : Life Cycle Assessment

LID : Low Impact Development Technology

SEMP : Strategic Environment Management Plan

Eco-eff : Eco-efficiency

Eco-suff : Eco-sufficiency

ReCipe : ReCipe Endpoint

AHP : Analytic Hierarchy Process

GREY : Grey evaluation

LCSA : Life-cycle Sustainability Assessment

Monte : Monte Carlo Simulation

EER : Eco-efficiency Ratio

Based on above previous studies that conducted researches about sustainable manufacturing especially adopting the life cycle assessment method, if this research is compared with the previous study then it comes to the different method and system boundaries that are being used. Most of the studies use cradle-to-grave but for authors from Indonesia, this approach is rarely used. As well as the LCA itself, this method is not so common to be conducted, so only few researchers conduct such of those research topics. Therefore, this research uses the cradle-to-grave system boundary approach. One thing that must be highlighted is that this research only examines raw material extraction until the product leaves factory, it has nothing to do with the disposal or recycling management, this is one point to distinguish this research among others. Then, as an improvement for the problem, this research uses eco-efficiency and output as EER (eco-efficiency ratio). Most of previous studies adopt method that will solve energy issues. That's why to distinguish with other study, simultaneously to avoid plagiarism and duplication, this research offers the solution by combining the eco-efficiency concept, life cycle costing and eco-efficiency ratio.

2.1.1 Inductive Reasoning

By considering the previous studies that are aligned with the problem case in PT. Tirta Investama, the LCA is the most suitable method in solving the problem in there. Since, PT. Tirta Investama must face the government penetration as to complete a certain document about environmental and sustainability of product to examine the sustainability of PET AQUA 1.5l, LCA as the best choice to be carried out. Thus, the system boundary and proposed solution should be considered.

Cradle-to-grave is adopted as the system boundary in this study. The system includes raw material extraction through the production process, to be transported to next point of sale either distribution center or retailer .The reason behind the utility of the system boundaries is to cover in large scope so it represents enough to examine the product life cycle even, yet do not touch the disposal or waste management. The system is bordered to the release of the products from factory (PT. Tirta Investama) and it excludes the customer behavior such as usage and the disposal due to lack of information and longer study requirement for further observation and customer survey.

Then, the method of LCA is carried out in examining the product life cycle because the LCA is the most suitable method and commonly used to know the environmental impact burdened in every single production of PET bottle. Therefore, an action plant should be taken to improve the performance in a broader perspective to create greater business value by considering the environmental (impact) performance of a company over time. This is why it comes to use eco-efficiency assessment as proposing the solution.

2.2 Deductive Study

2.2.1 Life Cycle Assessment

A. Definition of Life Cycle Assessment

Based on ISO 14040, life cycle assessment is best known for quantitative analysis of environmental aspects of a product over all its life cycle stages. Life-Cycle Assessment (LCA) – also called Life-Cycle Analysis – is one of the techniques to examine the impact of environment of certain product through every steps of its life – coming from the process of raw material extractions all the way through making it in factory, selling it to customer, using it in workplace or house until the disposal of the product (Bishop, 2000, p.252). The life-cycle also called as “from cradle to grave”. There are some basic terms that related and mostly discussed in LCA :

1. Products in here could be in the form of products (i.e car, chair, air-cond etc) and services (i.e procurement in free-way project).
2. Emission is something that has been released or emitted into the world. Car exhaust, burps, and radio broadcasts are all examples of emissions. The emission could be released through air, water and land, and resource consumption, constitute “environmental loads”.
3. Environment impacts in the LCA context, refers to adverse impacts on areas that should be safeguarded, such as ecosystem, human health, and natural resources.

More recently, some guidelines and principles relating to LCA studies were easily defined by ISO/TC 207/SC 5 using specific internationals standards, namely ISO 14040 (ISO 1996). The method which has already been accepted and the Draft International Standards (DIS) 14042 (Impact Assessment) and 14043 (Interpretation).

There were many initiatives to standardize the methodology of life-cycle assessment. The concept of life-cycle assessment first emerged in the late 1960's but did not receive much attention until the mid-11980's. In 1989, the Society of Environmental Toxicology and Chemistry (SETAC) became the first international organization to begin oversight of the advancement of LCA. In 1994, the International Standards Organization (ISO) began developing standards for the LCA as part of its 14000 series standards on environmental management. The standards address both the technical details and conceptual organization of LCA below:

1. ISO 14040-A standard on principles and framework
2. ISO 14041-A standard on goal and scope definition and inventory analysis
3. ISO 14042-A standard on life-cycle impact assessment
4. ISO 14043-A standard on life-cycle interpretation

The ISO-standard 14040 defines an LCA as following: “LCA is a technique for assessing the environmental impacts associated with a product, by:

1. Compiling an inventory of relevant inputs and outputs of a product system;
2. Evaluating the potential environmental impacts associated with those inputs and outputs;
3. Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study” (ISO 14040, 1996).

The main idea of cradle-to-grave analysis is simply illustrated in Figure 2.1. In each box represents the single unit or called as unit processes, as well as the inclusion of transport, diverse energy supply, co-products and so on. This scheme also turn into a simple ‘product trees’ which is diverse the raw material and energy supply, intermediate product until the waste management (including the recycling or disposal activities).

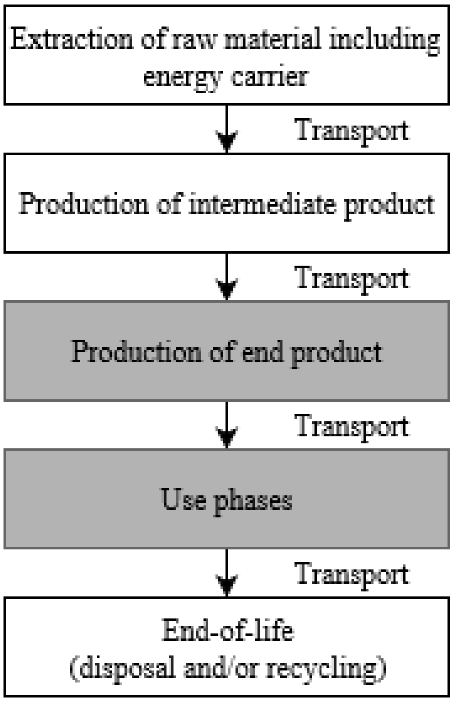

Figure 2.1 Simplfied life cycle of tangible product
Source : Klopffer and Grahl (2014)

Those boxes are then interconnected to form an entire system called as product system. The center is a product, a process, a service or, in a widest sense, a human activity (SETAC, 1993). In an LCA, systems are served with a specific function and therefore have specified performance that will be analyzed. Therefore, the quantified performance (avail) of a product system is the intrinsic standard of comparison (reference unit). It is the sole of basis for the definition of a ‘functional unit’ (ISO 14040, 2006).

The functional unit determination in this phase is critical as it is a reference to which all the inputs and outputs are related (Khasreen et al., 2009). According to Klopffer and Grahl (2014), the functional unit is the second basic term in an LCA, for example, the function of beverage packaging. Below are only some of the function that can be mapped with different packaging specifications:

1. 2000 0.5l reusable bottles of glass
2. 500 2l PET single-use bottles

Thus, for comparison packaging systems, which are three product systems above are roughly fulfil the similar function that will be compared and analyzed then. The weight, aesthetic or customer behavior are not important in this simplistic example so it can be neglected. It can be noted that the systems with match able function or almost performed the same function are compared. This is the reason why tangible product can also be compared with service as long as they have very similar function. Therefore, it is possible to compare the tangible product system with service system on the basis of equivalent function by means functional unit.

Erixon (1993) also stated that LCA actually has a strong correlation with the product can be through the relevant inventory, by processing from input of product until the output. From that activities then appear results shows the interpretation of the environmental impact based on the prior inventory analysis. Those processes are simply depicted in Figure 2.2, represents the life cycle of product from upstream to downstream activities.

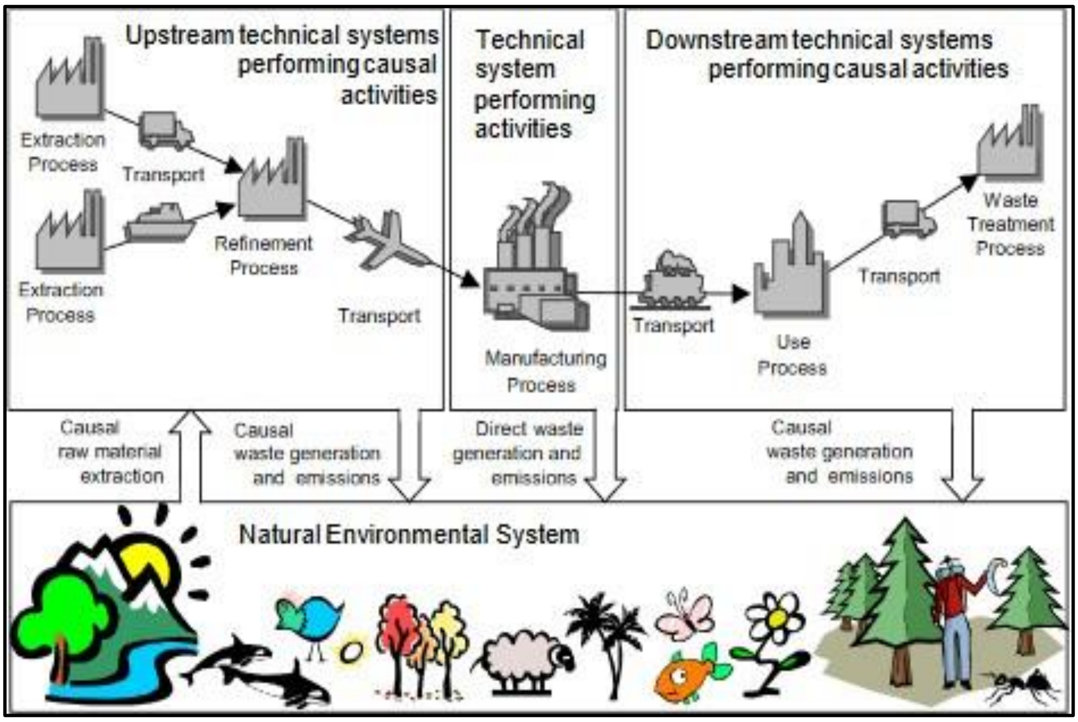

Figure 2.2 life cycle assessment scheme
Source : Carlson (1998)

According to Carlson (1998) also, the life cycle assessment involving some components system in which performing their job to conduct manufacturing process of certain product. Then of course, all these activities could not be ignored without natural resources system. The interaction between both natural environment system and through emission from plant causally via the upstream component like supplier. In order to interpret and environmentally assess the corporate activities, the corporate environmental information system also needs to include data on for example the natural environment (Saur, 1997).

Therefore, from above definition and studies about life-cycle assessment in general, can be overviewed as, one systematic-procedure that involving the way of a virgin material composed into something until the disposed of them, in which within those entire life-cycle of product, producing the undesirable residuals towards the environment and society. Moreover, if no action performed to control these residuals, resulting in unsustainability.

B. Objectives of Life Cycle Assessment

Based on ISO 14041 in 2006, LCA can provide space for development and standardization of a product design. This is obtained from the identification of each activity in the life cycle of a product to obtain a product that is environmentally friendly in terms of function and design. LCA can be used as a tool for the government in determining the energy and environmental policies of a company. The policy will affect business strategy, production and marketing systems, quality improvement, and determination of eco-labeling.

While, according to SETAC (1993), there are some primary objectives of carrying out the LCA are:

1. To provide a picture as possible of the interaction of any activities with its environment.
2. To contribute to the understanding of the interdependent nature of environment and also the consequences behind that; and
3. To provide decision-makers with information which defines environmental effects and opportunities to establish the improvement.

Therefore, based on above explanation, the core objectives of the LCA is presenting the impact and effects of environmental caused of any human activities with their natural resources, in opportunities to make environmental better by reducing the impacts on it.

C. Phases of Life Cycle Assessment

Studies on LCA were then developed to initialize the structure of LCA. It starts by identify and quantify the energy, material and environmental emission then assess or evaluate the impact of these uses and emissions. SETAC has also provide a basic structure of LCA called as SETAC triangle which is now becoming the basis standardizing of any activities related to LCA based on ISO. From the SETAC triangle, shown in Figure 2.3, it can be seen that there are four steps or phases involved in conducting LCA.

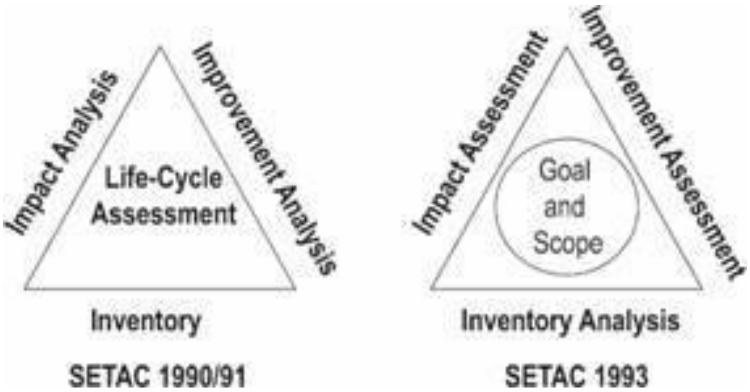

Figure 2.3 SETAC triangle in LCA

The inventory as quoted in above figure, in the context of LCA or LCI means the component that will be examine from cradle to grave is involving from the material and energy analysis as shown in Figure 2.4, the table contain list of the material from input until producing the output. These components then will form a product system. While for life cycle assessment framework shown in Figure 2.5.

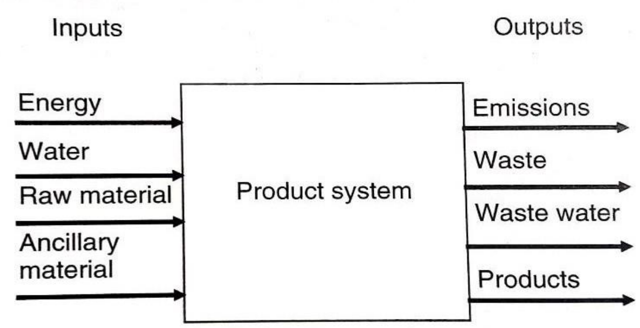

Figure 2.4 Analysis of matter and energy in product system (Klopffer, 2014)

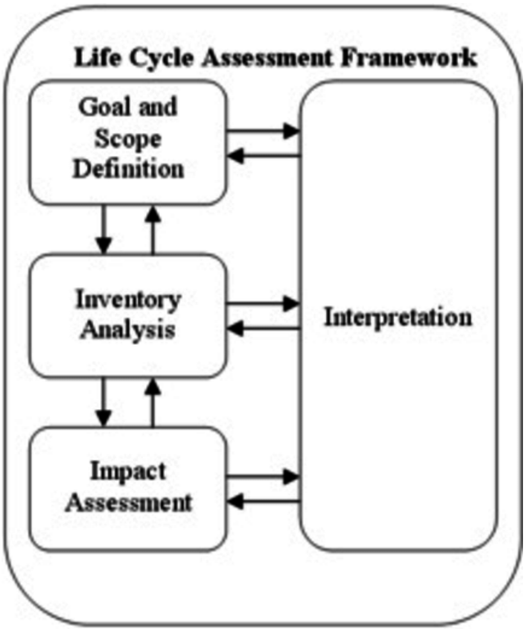

Figure 2.5 Life-cycle assessment framework
Source : ISO 14040

As essentially structured and maintained by ISO (1997, 2006) and SETAC, the phases of LCA have been renamed compared to earlier structure then the following terms are now widely used internationally:

1. Goal and scope definition
2. Life cycle inventory analysis
3. Life cycle impact assessment
4. Interpretation

Those phases in LCA would be defined and explained as following:

1. Goal and scope definition

   This is the very first step in life-cycle assessment and the most critical stages since this step identifies the purpose of study and mainly considered as the key of the study. In conducting the LCA, there are several elements are going to be declared such following:

   1. Establisihing the goal or the purpose of conducting the study.
   2. Defining the scope of the study that will include the technical system boundary, limitation and constraints, set many assumptions and functional unit.

Therefore, the goal of an LCA shall include the motivation for the study, intended application and audiences, initial data quality requirements and type of critical review (ISO, 1996). The ISO 14044 also reads that the goal and scope of an LCA shall be clearly defined and shall be consistent with the intended application. Due to the iterative nature of LCA, the scope may have to be refined during the study. The goal of a study should answer the following questions:

1. Range of application : what is the purpose of conducting the study?
2. Interest of realisation : why is the study adopt the LCA method?
3. Target group(s) : for whom will the LCA study be conducted?

The scope of LCA will then considered to set the assumptions, limitation and establish the functional unit of the study. The study also can perform the cut-off criteria in which regulating the exclusion of insignificants inputs into the product system resulting from some consideration. Based on ISO 14044 stated that there were 3 cut-off criteria shall be applied as well as for unit processes; mass, energy and environmental relevance. System boundary is a set of criteria specifying which unit processes are part of a product system. As shown in Figure 2.6, it illustrates the system boundary of corn Ethanol.

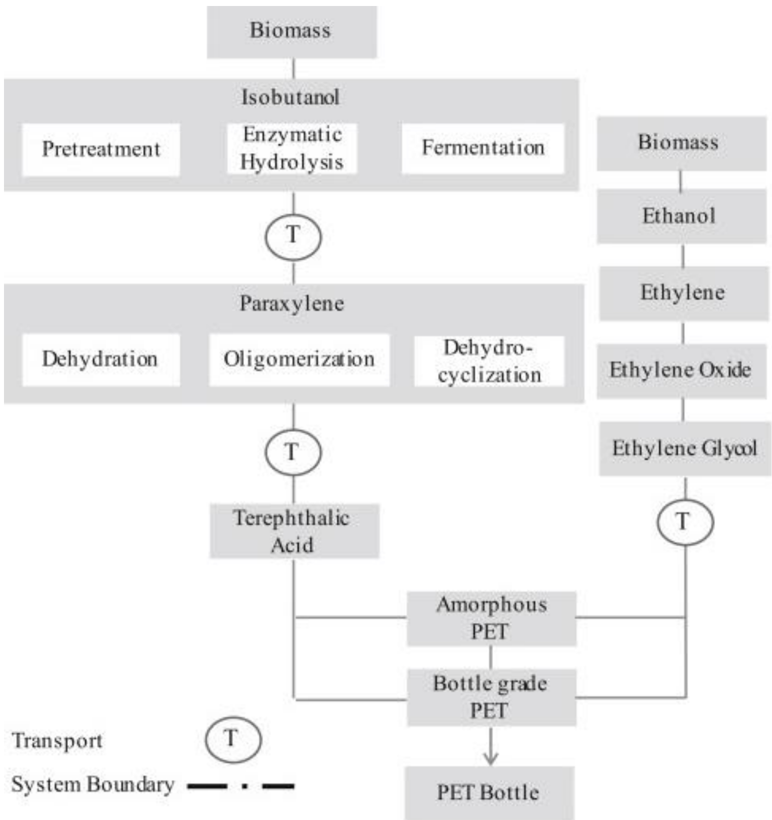

Figure 2.6 system boundary of fossil and bio-based PET bottles

Thus, it examines and receives inputs from the system and transfers output to it. There were four mainly system boundary according to ISO 14044:

1. Cradle-to-grave : include from raw material extraction through the production process, transported to next point of sale either distribution center or retailer then the end-of-life product (could be disposed or recycled).
2. Cradle-to-gate : include all process of raw material extraction through the production process (proceed in the manufacturing plant), then used to examine the environmental impact of the product.
3. Gate-to-grave : include all the process after production until end-life of its product, used to examine the environmental impact after leave for the factory.
4. Gate-to-gate : include the process of production only, used to determine the environmental impacts from the production's procedure or the process.

Then, defining the fU or functional unit is important, eventhough data acquisition initially does not need a fU, but it is urgently recommended to specify at the beginning of an LCA (Klopffer and Grahl, 2014). As shown in the Table 2.2 the example to declare the functional unit.

Table 2.2 Functional Unit in LCA

Product	**Functional Unit**
Disposable paper cup	Delivery of 16oz of cold-drink
Hot shower	Number of shower 20 minutes hot shower cycles
Photocopy machine	25exemplar sheets of paper copied
Gameboy	Years of use

The functional unit defines and ensures that the product that will be compared is on equal terms. The fU also helps to compare the overall environmental performance of different product systems in terms of impacts per unit of delivered service. Moreover fU later will be made to adjust and becoming a serious problem if not defining the fU and leads to serious data leaks. To define the functional unit shall deal with the reference flow.

2. Life cycle inventory analysis

Inventory Life Cycle Analysis produces a flow model in a technical system. The model describes the flow of mass and energy used throughout the system, data are needed that can be used to build the model. According to ISO standard 14040/2006, defines life-cycle inventory (LCI- analysis) is a phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its entire life cycle. The activities carried out in this step are:

1. Making a flow diagram made based on the system that has been made
2. Collecting data from all production activities along the system
3. Calculating the environmental load adjusted to the functional unit of each activity.

LCI contains a set of data according to the specifications needed. In its application, this data set is represented in the flow diagram of energy and material consumption and arranged in an A matrix or referred to as the Life Cycle Inventory (LCI). LCI data generated from an environment that is in accordance with the functional units produced from the production process. This environmental impact can occur due to exploitation of raw materials, composition of emissions in air, air, or soil (Erixon, 1993).

The numerical data would be needed to quantify the model from all activities from generating the inputs until the output. As depicted in the Figure 2.7, the form of numerical data contains:

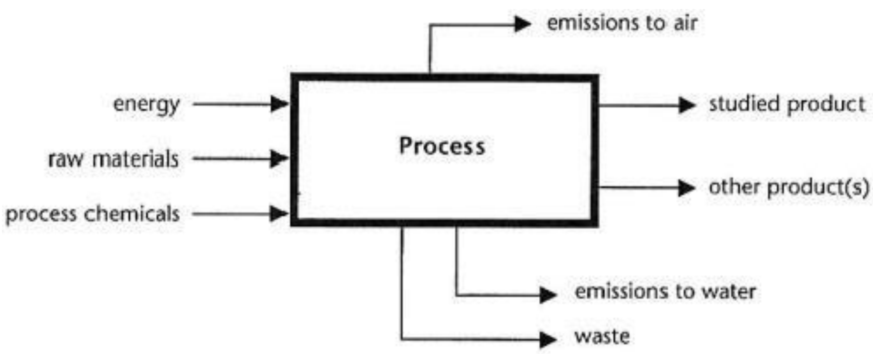

Figure 2.7 Input until out scheme in LCA (Hertwich, 2000)

1. Input ; raw material and energy used or other chemical processing. Such as, water, land, air area also could be in form of ancillary material.
2. Unit process n.
3. Output ; the product itself, emission, waste & other aspect environment.

3. Life cycle impact assessment

   Life Cycle Impact Assessment (LCIA) is the second predominantly scientific phase of life cycle assessment (Klopffer et al., 1999). In LCIA steps, some of the environmental impact from waste, emission, material and energy used cannot be manually calculated, so that impact assessment is needed. There are various of impact assessment methods, some of them are contains vary of impact categories that fit to the system observed. The methods are then chosen based on the goal when initially conduct the LCA, so that the output will correspondence to the goal setting. In the LCIA methods package also contains some of correspondence weight that will convert (automatically using software) into the impact indicator. Since each methods offer different impact categories, thus the flow that exposed from the activity have different impact to each other. Therefore, there are three main steps that will be conducted as below:

   1. Classification

      The first step in which the data from inventory analysis then grouped into some categories, depends on the environmental impacts that expected to contribute. Indicators of impact categories include; climate change, acidification, eutrophication, photochemical smog, fossil fuel depletion, ecotoxicity, ozone depletion and human toxicity.

   2. Characterization

      The second step that consist of weighting the different substances contribute towards the same environmental impact. Also to determine the potential effects of inputs and outputs on the category of environmental impacts. Each amount of raw material can then be converted into a number unit that indicates the potential for that impact.

   3. Assessment

The last step, where estimating the environmental impact that potentially the most urge and need to seek much attention. This result reflects from the characterization value. Actually, this is the most subjective stage of an LCA and is based on value judgments and is not scientific.

To simplify the LCIA step, Figure 2.8 shows some impact categories used as indicators, namely the baseline impact categories.

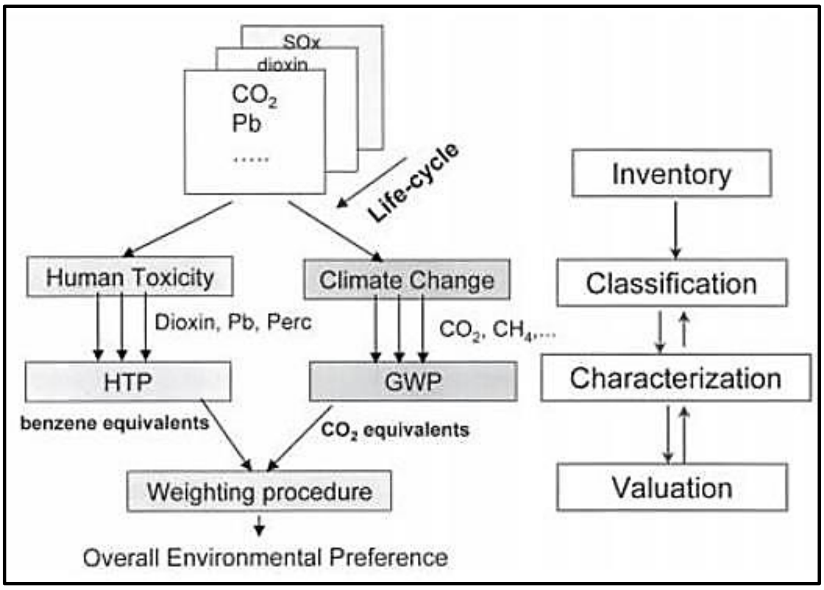

Figure **2.**8 Baseline categories on LCA (Hertwich, 2000)

4. Interpretation

   This is the last stage of LCA, where the results are considered to take the further action in order to perform improvement. It is also addressed to assess the results of the previous stages to determine the main impacts, analyze several alternative processes to reduce environmental impacts, consider environmental-friendly and approach the industrial ecology concept. This stage also evaluates and implements opportunities that arise to reduce environmental damage (Guinee et al., 2004).

2.2.2 Eco-efficiency Assessment

The term 'eco-efficiency' was coined by the World Business Council for Sustainable Development (WBCSD) in its 1992 publication 'Changing Course'. It is based on the concept of creating more goods and services while using fewer resources and creating less waste and pollution. According to the WBCSD definition, eco-efficiency is achieved through the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life-cycle to a level at least in line with the Earth's estimated carrying capacity'.

This concept refers to both ecological and economic performance must be complementary, which is realized by reducing the impact on environment and resource consumption. In other words, the company cannot only be oriented towards the company's profit but must also be concerned on the impact caused by the activities of the company.

There are three important messages in this concept according to Hansen and Mowen (2005). Firstly, improving ecological and economic performance. Second, improving the performance of environment should no longer be seen only as charity but as competition. Third, eco-efficiency is complementary and support sustainable development. While, according to the WBCSD, critical aspects of eco-efficiency are:

1. A reduction in the material intensity of goods or services;
2. A reduction in the energy intensity of goods or services;
3. Reduced dispersion of toxic materials;
4. Improved recyclability and greater durability of products;
5. Maximum use of renewable resources;

Eco-efficiency guarantees the sustainability of natural resources (material and energy). In the industry, this concept can be implemented through energy-saving (efficiency) use of raw materials, energy and water, minimization accident work and minimization of waste (Zaenuri et al., 2011).

From above explanation, it can be defined that the purpose of eco-efficiency is to reduce the environmental impact per unit produced and consumed. By reducing resources needed for the formation of better products and services, the business can reach profit because it has competitiveness.

In eco-efficiency is strongly correlated with the eco-cost since it is involving the life-cycle costing. Eco-costs are a measure to express the amount of environmental impact of a product on the basis of preventing the impact itself. This is a cost that has to be spent to reduce pollution and reduce the amount of material on earth. The concept of Eco-costs is the concept of shadow prices, where costs are a point where prevention costs meet the costs of damage produced in a system. However, calculations in Eco-costs results as in the cost of damage (TU Delft, 2015). There are some elements to get the result of eco-efficiency ratio (EER).

Barba-Gutierrez et al (2009) stated that to evaluate eco-efficiency, it takes a tool that is used one of them through data Envelopment Analysis (DEA). DEA is used in analyzing Eco-efficiency for consider several alternative solutions from the environmental improvement so that an optimum alternative is obtained. To attain this, the basic of linear program is generated in each solution or (supported) alternative that involving the previous result of LCA. Some of the economical aspect also considered here, such as the life cycle cost (LCC) from each alternative built. According to Kuosmanen and Kortelainen (2005), ECODEA is a linear program (LP) model to calculate the optimal Eco-efficiency ratio.

The LP model can be solved by the following equation:

$$Max\ z = Y_0 / \sum_{i=1}^{m} vixij \quad \ldots\ldots\ldots\ldots\ldots \text{(2.1)}$$

Subject to :

$$Y_j \times \sum_{i=1}^{m} vixij \ \leq 1,\ j = 1,\ \ldots,\ n \ \ldots\ldots\ldots\ldots\ldots\ldots \text{(2.2)}$$

$$V_r \geq 0 \ \ldots\ldots\ldots\ldots\ldots\ldots \text{(2.3)}$$

Where Y_0 = LCC from the first alternative. Because the LCC is the only output, the output multiplier is not needed in the model. Then the model is said to be eco-efficient when z = 1. To complete the model as a linear program, the equation in the model is inverse to produce the eco-efficiency ratio as below:

$$min^{-1} z = 1 / Y_0 \times \sum_{i=1}^{m} vixij \quad \ldots\ldots\ldots\ldots (2.4)$$

Subject to

$$1 / Y_j \times \sum_{i=1}^{m} vixij \quad \geq 1,\ j=1, \ldots\ldots, \quad \ldots\ldots\ldots (2.5)$$

$$\geq 0 \ \ldots\ldots\ldots \quad (2.6)$$

Where:

Yj= *Life cycle cost*

vi= *Life cycle impact categories*

xij= *Corresponding weights*

Vr = Optimal weights

Above mathematical model will be then solved using linear programming (LP) and the highest rank from eco-efficiency ratio will then could be consider as the optimum solution.