

## *Chapter 2*

# Theoretical Background



## 2.1 Indonesian Government Policy on Biodiesel Energy and Environment

### 2.1.1 Law of the Republic of Indonesia number 30 of 2007 concerning energy

Article 1, paragraph 10, reads: the environment is a unitary space with all objects, forces, conditions, and living things, including humans and their behavior, which affect the continuity of life and the welfare of humans and other living creatures. Paragraph 11 states: the preservation of environmental functions is a series of efforts to maintain the continuity of the carrying capacity and capacity of the environment. Paragraph 25 states: the national energy policy is an energy management policy based on the principles of justice, sustainability, and environmental insight in order to create independence and national energy security (President of the Republic of Indonesia, 2007)

LCA study of biodiesel production is related to the law of the Republic of Indonesia Number 30 of 2007 concerning energy, namely article 1, paragraphs 10, 11, and 25. The definition of the environment (Paragraph 10) and the preservation of environmental functions (Paragraph 11) are contained in the law on energy that shows the importance of protecting the environment and preserving environmental functions in the energy sector. Paragraph 25 states that the national energy policy must be environmentally sound (President of the Republic of Indonesia, 2007).

### 2.1.2 Presidential Regulation of the Republic of Indonesia number 5 of 2006 concerning national energy policy

Article 2, Paragraph 2, states: the targets of the national energy policy are: a. The achievement of energy elasticity is less than 1 (one) in 2025. b. The realization of the optimal (primary) energy mix in 2025, namely the role of each type of energy in national energy consumption: 1) Petroleum becomes less than 20% (twenty percent). 2) Natural gas to be more than 30% (thirty

percent). 3) Coal becomes more than 33% (thirty three percent). 4) Biofuels to be more than 5% (five percent). 5) Geothermal energy becomes more than 5% (five percent). 6) Other new and renewable energy, in particular, biomass, nuclear, small-scale hydropower, solar power, and wind power to more than 5% (five percent). 7) Other fuels originating from coal liquefaction are more than 2% (two percent) (President of the Republic of Indonesia, 2006).

The research topic of LCA of biodiesel production is related to the regulation of the President of the Republic of Indonesia number 5 of 2006 concerning national energy policy, article 2, paragraph 2, point b mentions the realization of optimal primary energy (mix) in 2025, namely the role of each type of energy in consumption one of the national energy sources is biofuel, which is more than 5% (five percent) (President of the Republic of Indonesia, 2006).

### 2.1.3 Law of the Republic of Indonesia number 32 of 2009 concerning environmental protection and management

Article 1, paragraph 19 states: climate change is a change in climate that is caused directly or indirectly by human activities so that it causes changes in the composition of the atmosphere globally and besides that it is also in the form of changes in natural climate variability observed in comparable time periods. Paragraph 26 states: environmental impact is the effect of changes to the environment caused by a business and/or activity. Paragraph 34 states: a serious threat is a threat that has a wide impact on the environment and causes public unrest (President of the Republic of Indonesia, 2009).

LCA study of biodiesel production is related to the law of the Republic of Indonesia number 32 of 2009 concerning environmental protection and management, article 1, paragraph 19, paragraph 26, paragraph 34. This study calculates global warming. Global warming can cause global climate change. Paragraph 19 discusses climate change caused by human activities. Global warming can make ice in the Polar Regions melt which will have an impact on rising

sea levels. Paragraph 26 mentions the environmental impact. According to the United Nations Development Programs (2007), there are several main threats from climate change to people's lives, especially the poor, including sources of livelihood, health, food security, and water. It is a serious threat to society. Paragraph 34 says about serious threats.

## **2.2 Biodiesel and Its Characterization**

Biodiesel is an alternative fuel consisting of mono alkyl esters of long chain fatty acids. Biodiesel is formed through the reaction between ester compounds with methanol or ethanol and comes from renewable sources such as vegetable oils or animal fats. Biodiesel is intended as a non-renewable substitute for diesel fuel. Biodiesel has chemical and physical properties similar to petroleum diesel so it can be used directly for diesel engines or mixed with petroleum diesel (Arita et al., 2008).

The use of biodiesel provides several advantages including being safer in handling and storage because it has a higher boiling point (150-180 °C) compared to conventional diesel (70 °C), does not produce harmful vapors at room temperature, is biodegradable, non-toxic, and environmentally friendly (Odi & Niamul, 2014). Biodiesel is also capable of reducing the greenhouse effect, and the use of biodiesel can improve local air quality by reducing emissions of harmful gases such as carbon monoxide (CO), ozone (O<sub>3</sub>), sulfur dioxide (SO<sub>2</sub>), and other reactive hydrocarbons (Arita et al., 2008).

Biodiesel characterization can be seen from various aspects including:

### **1. Density**

Density shows the ratio of mass per unit volume. The characteristic is related to the calorific value and power produced by the diesel engine per unit volume of fuel (Dedi, 2012).

### **2. Viscosity**

Viscosity is an intrinsic property of the fluid that indicates the resistance of the fluid to its flow, because friction in the fluid moving from one place to another affects the atomization of the fuel by injection into the combustion chamber, resulting in deposition of the engine. High viscosity or thicker fluid will result in slower flow velocity so that the process of fuel atomization degree will be hampered in the combustion chamber (Dedi, 2012).

### 3. Cetane number

The cetane number indicates the quality of the diesel fuel. The scale for cetane numbers usually uses a reference in the form of a mixture of normal cetane ( $C_{16}H_{34}$ ) and alpha methyl naphthalene ( $C_{10}H_7CH_3$ ). Normal cetane has a cetane number of 100, alpha methyl naphthalene has a cetane number of 0, and hepta methyl nonane has a cetane number of 15. Good fuels have a high cetane number so ignition can occur immediately, a low cetane number can cause knocking on the machine (Yanowitz et al, 2014).

### 4. Water content

The water content in the oil is one of the benchmarks for the quality of the oil. The smaller the water content in the oil, the better the quality, this can reduce the possibility of a hydrolysis reaction which can cause an increase in free fatty acid levels, the water content in the fuel can also cause a decrease in the heat of combustion, foaming and is corrosive if it reacts with sulfur because it will form acid (Dedi, 2012).

### 5. Acid number

The acid number is the number of milligrams of KOH required to neutralize free acids in a 1-gram sample of biodiesel based on SNI 7182:2015 (National Standardization Agency, 2015).

### 6. Saponification number

The saponification number is the number of milligrams of KOH required to saponify 1-gram fat under certain conditions based on SNI 7182:2015 (National Standardization Agency, 2015).

## 7. Total glycerol

Glycerol is a by-product of the transesterification of triglycerides. The total glycerol content contained in biodiesel must be of small value based on SNI 7182:2015 (National Standardization Agency, 2015).

## 8. Methyl ester

Methyl ester is the result of transesterification of triglycerides contained in vegetable oils. Methyl ester is a parameter for the success of biodiesel production from vegetable oil based on SNI 7182:2015 (National Standardization Agency, 2015).

## 9. Iodine Number

The iodine value is related to the level of unsaturation of the fatty acid esters that make up biodiesel. Samples that have a high level of unsaturation (containing many double bonds) will bind large amounts of iodine, so that the value of the iodine number is higher. High iodine number correlates with low oxidative stability. That is, the higher the iodine number, the more susceptible biodiesel is to oxidation reactions, so it will tend to cause polymerization which will form deposits in the engine (Musadhaz et al., 2012). Based on the National Standardization Agency (2015), the biodiesel quality requirements based on SNI 7182:2015 is shown in Table 2.1:

**Table 2.1.** Biodiesel quality requirements

No	Parameter	Unit	Requirements	Test Method
1	Density (40 °C)	kg/m <sup>3</sup>	850-890	ASTM D 1298
2	Kinematic viscosity (40 °C)	mm <sup>2</sup> /s	2,3-6,0	ASTM D 445
3	Cetane number	-	Min. 51	ASTM D 613
4	Flash point	°C	Min. 100	ASTM D 93
5	Cloudy point	°C	Max. 18	ASTM D 2500
6	Carbon residue	%mass	Max. 0,05	ASTM D 4530
7	Water and sediment	%vol	Max. 0,05	ASTM D 2709
8	Sulfated ash	%mass	Max. 0,02	ASTM D 874
9	Free glycerol	%mass	Max. 0,02	AOCS Ca 14-56
10	Total glycerol	%mass	≤ 0,24	ASTM D 6584
11	Methyl ester content	%mass	Min. 96,5	-
12	Iodine number	g I <sub>2</sub> /100g	Max. 115	AOCS Cd 1-25
13	Phosphorus content	mg/kg	Max. 10	AOCS Ca 12-55

No	Parameter	Unit	Requirements	Test Method
14	Acid number	mgKOH/g	Max. 0,5	ASTM D 664
15	Saponification number	mgKOH/g	≤ 261.26	EN 15751
16	Oxidation stability	minute	360	EN 15751

## 2.3 Palm Oil

The constituent components of palm oil consist of triglycerides and non-triglycerides. Components in large amounts are found in triglycerides. Triglycerides consist of saturated fatty acids and unsaturated fatty acids. Fatty acids themselves range from oleic acid 40% (unsaturated fatty acids), linoleic acid 10% (unsaturated fatty acids), palmitic acid 44% (saturated fatty acids), and stearic acid 4.5% (saturated fatty acids) which generally have balanced proportion between saturated and unsaturated fatty acids. The following is Table 2.2 of the fatty acid composition contained in palm oil (Arianing, 2018).

**Table 2.2.** Fatty acids composition of palm oil

Types of fatty acids	Names of fatty acids	% of total fatty acids	
		Range (% mass)	Average (% mass)
Saturated fatty acids	Lauric acid (C <sub>12</sub> H <sub>24</sub> O <sub>2</sub> )	0.1-1.0	0.2
	Myristic acid (C <sub>14</sub> H <sub>28</sub> O <sub>2</sub> )	0.9-1.5	1.1
	Palmitic acid (C <sub>16</sub> H <sub>32</sub> O <sub>2</sub> )	41.8-45.8	44.0
	Stearic acid (C <sub>18</sub> H <sub>36</sub> O <sub>2</sub> )	4.2-5.1	4.5
Unsaturated fatty acids	Palmitoleic acid (C <sub>16</sub> H <sub>30</sub> O <sub>2</sub> )	0.1-0.3	0.1
	Oleic acid (C <sub>18</sub> H <sub>34</sub> O <sub>2</sub> )	37.3-40.8	39.2
	Linoleic acid (C <sub>18</sub> H <sub>32</sub> O <sub>2</sub> )	9.1-11.0	10.1
	Linolenic acid (C <sub>18</sub> H <sub>30</sub> O <sub>2</sub> )	0.0-0.6	0.4
	Arachidonic acid (C <sub>20</sub> H <sub>32</sub> O <sub>2</sub> )	0.2-0.7	0.4

## 2.4 Used Cooking Oil

Cooking oil that has been used several times undergoes chemical changes due to oxidation and hydrolysis so that it can cause damage to the cooking oil. Through this process, some triglycerides will break down into other compounds, one of which is free fatty acid (FFA). This free fatty acid content will then be esterified with methanol to produce biodiesel. The fatty acid content and characteristics of used cooking oil is shown in Table 2.3 (Elma et al., 2016):

**Table 2.3.** Fatty acids composition of used cooking oil

Types of fatty acids	Names of fatty acids	% of total fatty acids Average (%mass)
Saturated fatty acid content	Myristic acid (C <sub>14</sub> H <sub>28</sub> O <sub>2</sub> )	0.9
	Palmitic acid (C <sub>16</sub> H <sub>32</sub> O <sub>2</sub> )	20.4
	Stearic acid (C <sub>18</sub> H <sub>36</sub> O <sub>2</sub> )	4.8
	Behenic acid (C <sub>22</sub> H <sub>44</sub> O <sub>2</sub> )	0.03
	Tetracosanoic acid (C <sub>24</sub> H <sub>48</sub> O <sub>2</sub> )	0.04
Unsaturated fatty acid content	Palmitoleic acid (C <sub>16</sub> H <sub>30</sub> O <sub>2</sub> )	4.6
	Oleic acid (C <sub>18</sub> H <sub>34</sub> O <sub>2</sub> )	52.9
	Linoleic acid (C <sub>18</sub> H <sub>32</sub> O <sub>2</sub> )	13.5
	Linolenic acid (C <sub>18</sub> H <sub>30</sub> O <sub>2</sub> )	0.8
	Eicosenoic acid (C <sub>20</sub> H <sub>38</sub> O <sub>2</sub> )	0.84
	Arachidonic acid (C <sub>20</sub> H <sub>32</sub> O <sub>2</sub> )	0.12
	Erucic acid (C <sub>22</sub> H <sub>42</sub> O <sub>2</sub> )	0.07

## 2.5 Soybean Oil

The fatty acids in soybean oil are predominantly unsaturated fatty acids and saturated fatty acids. Soybean oil contains around 15% saturated fatty acids and approximately 85% unsaturated fatty acids. Table 2.4 shows the fatty acid composition of soybean oil (Abdelghany et al., 2019).

**Table 2.4.** Fatty acids composition of soybean oil

Types of fatty acids	Names of fatty acids	% of total fatty acids Range (%mass)
Saturated fatty acid content	Stearic acid (C <sub>18</sub> H <sub>36</sub> O <sub>2</sub> )	2.2–5.5
	Palmitic acid (C <sub>16</sub> H <sub>32</sub> O <sub>2</sub> )	10.3–15.33
Unsaturated fatty acid content	Oleic acid (C <sub>18</sub> H <sub>34</sub> O <sub>2</sub> )	13.3–46.0
	Linoleic acid (C <sub>18</sub> H <sub>32</sub> O <sub>2</sub> )	34.6–63.4
	Linolenic acid (C <sub>18</sub> H <sub>30</sub> O <sub>2</sub> )	4.3–13.7

## 2.6 Canola Oil

Canola oil is a kind of vegetable oil derived from the canola flower. Canola oil has a high fatty acid content, making it an excellent biodiesel feedstock. Canola oil contains the largest concentrations of saturated and unsaturated fatty acids, with palmitic acid accounting for 3.9 % and oleic acid accounting for 60.2 %. Table 2.5 shows the fatty acid makeup of canola oil (Yuan et al., 2005).



**Table 2.5** Fatty acid composition of canola oil

Types of fatty acids	Names of fatty acids	% of total fatty acids
		Average (%mass)
Saturated fatty acid content	Myristic acid (C <sub>14</sub> H <sub>28</sub> O <sub>2</sub> )	0.1
	Stearic acid (C <sub>18</sub> H <sub>36</sub> O <sub>2</sub> )	3.1
	Palmitic acid (C <sub>16</sub> H <sub>32</sub> O <sub>2</sub> )	3.9
Unsaturated fatty acid content	Erucic acid (C <sub>22</sub> H <sub>42</sub> O <sub>2</sub> )	0.5
	Oleic acid (C <sub>18</sub> H <sub>34</sub> O <sub>2</sub> )	60.2
	Linoleic acid (C <sub>18</sub> H <sub>32</sub> O <sub>2</sub> )	21.1
	Linolenic acid (C <sub>18</sub> H <sub>30</sub> O <sub>2</sub> )	11.1

## 2.7 Sunflower Oil

Because of its high fatty acid content, sunflower may be utilised as a raw material for biodiesel. Sunflower oil contains both saturated and unsaturated fatty acids. Palmitic acid accounts for 5.9 percent of the saturated fatty acids in sunflower oil, whereas linoleic acid accounts for 58.2 % of the unsaturated fatty acids (Turhan et al., 2010). Table 2.6 shows the fatty acid makeup of sunflower oil.

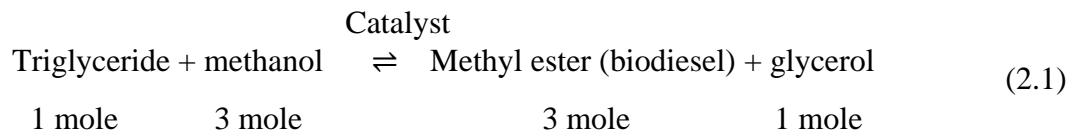
**Table 2.6.** Fatty acids composition of sunflower oil

Types of fatty acids	Names of fatty acids	% of total fatty acids
		Average (%mass)
Saturated fatty acid content	Stearic acid (C <sub>18</sub> H <sub>36</sub> O <sub>2</sub> )	4.9
	Palmitic acid (C <sub>16</sub> H <sub>32</sub> O <sub>2</sub> )	5.9
Unsaturated fatty acid content	Oleic acid (C <sub>18</sub> H <sub>34</sub> O <sub>2</sub> )	29.2
	Linoleic acid (C <sub>18</sub> H <sub>32</sub> O <sub>2</sub> )	58.2

## 2.8 Biodiesel Production

Biodiesel is produced through a transesterification reaction in vegetable oils. Vegetable oil must have a low acid value to be used in the transesterification process. Transesterification or alcoholysis is the exchange reaction of an alcohol group from one ester with another. In biodiesel production, transesterification is carried out on the raw material in the form of vegetable oil. In transesterification of vegetable oils, triglycerides react with alcohol in the presence of a strong acid or strong base as a catalyst to produce a mixture of fatty acid alkyl

esters and glycerol. The addition of a base catalyst will accelerate the transesterification reaction in the formation of esters (Istadi, 2011). The alcohols that can be used in the transesterification of triglycerides are methanol, ethanol, propanol, butanol, and amyl alcohol. Methanol is often used in transesterification reactions for biodiesel production. The transesterification reaction between natural oils or fats with methanol is seen as follows:



One mole of triglyceride reacts with three moles of methanol to produce three moles of methyl ester and one mole of glycerol. This methyl ester is referred to as biodiesel. Catalyst serves to speed up the transesterification reaction without participating in the reaction. Transesterification with a base catalyst is considered more advantageous when compared to an acid catalyst because the transesterification time on a base catalyst is shorter and the temperature used is also lower. Base catalysts that can be used in transesterification are strong bases such as sodium hydroxide (NaOH) and potassium hydroxide (KOH) (Istadi, 2011).

The transesterification process in biodiesel production is influenced by several factors (Manurung, 2006), namely:

### 1. Temperature

The transesterification process can take place faster if the temperature used during the process is close to the boiling point of the alcohol used.

### 2. Stirring speed

The higher the stirring speed, the higher the molecular motion will cause collisions. Then there will be diffusion between the oil to form alkyl esters.

### 3. Catalyst type

There are two types of catalysts that can be used, namely acid and alkaline catalysts. The type of catalyst used will affect the transesterification time, the use of an acid catalyst will require a longer transesterification time when compared to an alkaline catalyst.

#### 4. Comparison of alcohol – fatty acids

Transesterification is a reversible reaction, the use of excess alcohol will encourage the reaction towards the formation of alkyl esters.

#### 5. Water content

The presence of water will affect the transesterification lowering the conversion of alkyl esters. When an acid catalyst is used, the presence of water can direct the reaction to form a carboxylic acid so that the resulting alkyl ester decreases. When an alkaline catalyst is used, the presence of water will result in a saponification reaction which will reduce the yield and complicate the glycerol separation process due to the formation of an emulsion.

## **2.9 Diverse Methods for Analysing Environmental Impact**

### **2.9.1 Overlay method**

The overlay method is used often and effectively in land use planning. This method involves the use of overlapping maps, each of which represents a significant environmental or geographical aspect. For the selection and identification of different sorts of resulting effects, an efficient overlay method is used. Each map displays comprehensive environmental components, including physical, chemical, biological, socioeconomic, and sociocultural factors. The overlay approach employs a number of maps depicting the construction site and the surrounding region. Merging in the form of patching reveals a collection or arrangement of the region's environmental circumstances (Raharjo, 2007).

Overlay is a visual information system created by integrating many distinct maps (each with its own information/database). This compilation of distinct maps, or what is often known as a composite map, may give a broader and more diverse variety of information. Each transparency map contains information on environmental and societal factors. The resulting composite map will offer an overview of the project's clash with environmental realities. This strategy cannot ensure that it will accommodate all possible consequences, but it may offer prospective implications on certain geographical regions. For instance, a map of a dam in a dam project will indicate the possibility for floods, which may be superimposed with maps of animal habitats, human activity, etc (Raharjo, 2007).

### 2.9.2 Checklist method

The checklist method is one of the informal ways of observation in which the observer determines the behavioural indicators to be observed in one table. Checklist is a recording system with two recording modes, open and closed. This method has a high degree of selectivity since the observed behaviour is very selective, and it has a high degree of inference because the observer concentrates only on the specified behaviour category (Soemarwoto, 2005).

As a theoretical foundation for this style of observation, the observer must first identify the behavioural indicators collected from books, journals, scientific papers, and other literatures. The observer then compiles all the indications into a single indicator table and adds a description table and coding table beside it. The description table is where particular behaviours are recorded. During the observation, the observer only provides a sign in the form of a plus (+) if the behaviour appears in the coding table, or a minus (-) if the behaviour does not exist in the coding table, if the subject exhibits a behaviour mentioned in the indicator table. This method was chosen because it is easy and straightforward, allowing just the desired action to be emphasized (Soemarwoto, 2005).

### 2.9.3 Matrix method

The matrix method employs a two-dimensional checklist, consisting of a horizontal list of development activities with the potential to generate consequences and a vertical list of environmental components that may be impacted. Leopold, Moore, and Fisher and Davies interaction matrix are among the most well-known interaction matrix methodologies (Raharjo, 2007).

#### 2.9.3.1 Leopold interaction matrix method

The method of Leopold's interaction matrix is a matrix of 100 types of activities from a project with 88 environmental components. The characterization of the project's environmental consequences is expressed in terms of interactions between activities and environmental components (Suratmo, 2004).

After the matrix is constructed, the first step is to assess the environmental effect of each project activity. If it is expected that an action would have an effect on an environmental component, the intersection box between the two is diagonally indicated (Suratmo, 2004).

The second stage is to identify the dimensions and significance of each diagonal box. Together with the projected effects, they are stated as numerical values or on a scale from one to ten, and each number is accompanied with a clear explanation or criterion. One is the least significant number, whereas ten is the most. The development of the scale should be predicated on an objective appraisal of the value. Positive effects are denoted with a plus sign ('+'), whereas negative effects are denoted with a minus sign ('-') (Suratmo, 2004).

#### 2.9.3.2 Moore interaction matrix method

The distinguishing feature of Moore's method is that environmental consequences are seen from the perspective of the influence on groupings of regions that have been or are being exploited by people, or other human development initiatives. The Moore approach is based on

the examination of the causes or creators of genuine environmental consequences, as well as the identification of direct and indirect impacts on other resources utilised by people or other regions of usage. Moore's Matrice is divided into six distinct categories, including the originating activity and related activities, the potential for environmental change, the major environmental impacts, the human use affected, the potential damage caused by the activity, and the overall magnitude of the potential reduction in human use (Raharjo, 2007).

### 2.9.3.3 Fisher and Davies interaction matrix method

This method is unique in that three distinct types of matrix are arranged in phases. Before a project is constructed, the environmental baseline consists of a matrix for environmental assessment. The second level, compatibility matrix with the environment. The third phase involves the choice matrix (Soemarwoto, 2005).

In the first step, a matrix of essential environmental components is assembled, appraised, and ranked on a scale of significance at the time of research and management sensitivity. The interdisciplinary team must first undertake a field orientation to identify the limits of the study, since the boundaries of the oriented region would be influenced either directly or indirectly.

The matrix created at this step is the environmental impact matrix. The structure of the matrix is almost identical to that of the Leopold matrix, with the exception that the environmental components and kinds of activities contained in this matrix have a simpler structure. Each activity's influence on an environmental component is denoted with a plus sign (+) for a positive impact and a minus sign (-) for a negative impact. The impact duration is denoted by the letters S (short) for short-term effect and L (long) for long-term impact (Soemarwoto, 2005).

In the third step of decision matrix preparation, a decision matrix is constructed. The matrix is constructed on the basis of the relationship between the criteria for environmental components

that will be affected on a scale of 4 and 5, both positively and negatively, from the second stage alternative matrix, namely environmental conditions without a project and environmental conditions with a project. In collecting the column of decision-making criteria, it is necessary to examine decision-making criteria such as those who will be impacted, uncertainty, remuneration, management requirements, diversity, etc (Soemarwoto, 2005).

#### 2.9.4 Network method

The network method is a list of connected project operations and environmental components that are impacted. Then, the two lists are recompiled to demonstrate the flow of affects resulting from a project activity. This impact flow's structure explains the direct and indirect affects, as well as the link between environmental components, so that a global impact review may be conducted to determine which major activities can be controlled. It is the evolution of the matrix method in order to remove the matrix's shortcomings. This network's flaws and structure can only reveal the impact's flow, not its positive or negative nature. In addition, information on the impact's magnitude was not supplied (Raharjo, 2007).

#### 2.9.5 Life cycle assessment method

Life cycle assessment (LCA) is used to quantify the environmental effect of a process for producing goods and services. In the LCA framework, all phases of a product's life cycle will be taken into account. The life cycle may encompass the process of acquiring raw materials, processing materials for manufacturing, waste and emissions created during the production process, and waste and emissions generated after the product has been used. The following diagram illustrates the limits of LCA. Definition of goals and scope, LCI (Life Cycle Inventory), impact assessment (Life Cycle Impact Assessment), and interpretation are the steps of the LCA study framework (ISO 14040, 2006).

The Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 1 of 2021 pertaining to the Company Performance Rating Program in Environmental Management stipulates the adoption of LCA in the Company Performance Rating Program (PROPER). The purpose of this requirement is to: (i) urge enterprises to comply with laws and regulations via reputation incentives and disincentives, and (ii) encourage companies with excellent environmental performance to adopt clean production and future plans in achieving sustainable development. In other words, LCA may be seen as a sort of environmental impact analysis (AMDAL) refinement (Overlay Method, Checklist, Matrix, and Network) for measuring the influence on the environment.

Compared to the Overlay, Checklist, Matrix, and Network Methods, the LCA Method can undertake a comprehensive evaluation of each manufacturing unit's production process. By performing LCA, the energy and water consumption of each production unit may be determined, allowing for the identification of wastes that may result from certain process units. LCA study may also identify the influence on a number of other types of environmental harm. Advantages of the LCA itself include a complete and extensive analysis. Ultimately, this LCA method generates EPD (Environmental Product Declaration) like Ecolabel III, which may raise the product's resale value and benefit the company (Minister of Environment and Forestry of the Republic of Indonesia, 2021).

## **2.10 Life Cycle Assessment**

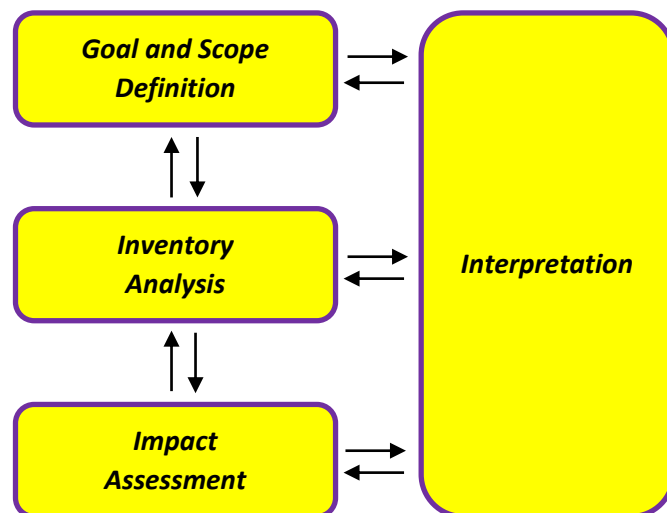
ISO 14040 (2006) defines LCA as a collection of assessments of inputs, outputs, and possible environmental consequences across the life cycle of a product system. LCA is a research and assessment of the environmental effect produced by the existence of a certain product. LCA measures the complete life cycle of a product. LCA is commonly referred to as the cradle-to-grave analysis, which may begin with the extraction of raw materials from the earth to



manufacture goods and finish with the return of all materials to the earth. The LCA scope is separated into four categories: cradle-to-grave, cradle-to-gate, gate-to-gate, and cradle-to-cradle. Cradle to grave (raw material to waste), cradle to gate (raw material to product), gate to gate (one step to another stage), and cradle to cradle (raw material to the process of recycling trash into raw material or an ecologically pleasant waste environment). The idea of life cycle assessment permits the use of acceptable and well-defined assumptions (ISO 14040, 2006).

The majority of life cycle assessment (LCA) research on agricultural bioenergy have focused on global warming potential (GWP) (Bernesson et al., 2006). In recent years, life cycle assessment has assumed a central role in the formulation of environmental policy. The European Union's communication of the IPP (Integrated Product Policy) idea provides an excellent illustration. Numerous affluent nations (including the United States, Germany, and China) have created life cycle assessment promotion policies. Another trend is the drive toward sustainable reporting. Numerous businesses now report on the sustainability of their operations (Goedkoop et al., 2010).

Basically, the LCA study consists of four distinct, but interrelated phases. The following Figure 2.1 is an LCA framework according to ISO 14040



**Figure 2.1.** LCA framework according to ISO 14040:2006

Based on Figure 2.1, the LCA step begins with determining the goal and scope definition (objective and scope of the study), followed by inventory analysis (analysis of the inventory of all emission parameters and source consumption), impact assessment (impact assessment method) and interpretation (interpreting the results).

### 1. Goal and scope definition

The objectives and scope of the LCA are guidelines that provide direction and assistance to ensure the consistency of the LCA being carried out (ISO 14040, 2006):

1. The reasons for carrying out the LCA and the questions that need to be answered.
2. A precise definition of the product, its life cycle and the functions it fulfills.
3. Definition of comparison basis (functional unit) when products should be compared.
4. Description of system boundaries.
5. Explanation of how to handle allocation problems.
6. Data quality requirements.
7. Assumptions and limitations.
8. Requirements related to LCIA (life cycle impact assessment) procedures

### 2. Inventory analysis

The inventory analysis phase involves flow allocation and release, data collection and calculation procedures to measure the related inputs and outputs of the product system. Data collection can be achieved through the use of relevant built-in data in the LCA software and/or the use of specific data generated from the system (Debalina & Ralph, 2013).

### 3. Impact assessment

The impact assessment phase of the LCA is defined as the phase aimed at evaluating the magnitude of the potential environmental impact of a product or system. The life cycle

inventory (LCI) results provide information for the life cycle interpretation stage through the impact assessment stage, which involves (ISO 14040, 2006):

1. Selection and definition of impact categories (mandatory): identify relevant environmental impact categories (e.g. global warming, acidification, terrestrial toxicity).
2. Classification (mandatory): assigning LCI results to an impact category (e.g. classifying carbon dioxide emissions to global warming).
3. Characterization (mandatory): modeling LCI impacts in impact categories using science-based conversion factors (e.g. modeling potential impacts of carbon dioxide and methane on global warming).
4. Single score (optional): emphasizes the most important potential impact.

#### 4. Interpretation

Interpretation is the LCA phase where the findings are from the inventory analysis and impact assessment. This phase also provides results that are consistent with the stated objectives and scope and reaches conclusions explaining boundaries and providing recommendations (ISO 14040, 2006).

## **2.11 CML 2 Baseline 2000**

CML 2 Baseline 2000 is one of the life cycle impact assessment methods. CML 2 Baseline 2000 takes into account impacts including: abiotic depletion, acidification, eutrophication, global warming, human toxicity, freshwater ecotoxicity, marine ecotoxicity, terrestrial ecotoxicity, and photochemical oxidation.

### 1. Global warming

Global warming potential (GWP) is the potential contribution of a substance to the greenhouse effect. This value has been calculated for a number of substances over a period of 20, 100 and 500 years because it is clear that certain substances gradually decompose and will become inactive in the long term. For the CML 92 method, have been using GWP for 100 years as it is the most common choice.

CML has added values for CFC (hard) and for CFC (soft) to the CML method (1992), due to it is not always known which CFC was released. The GWP for this category of substances has been equated with CFCs which are often used in mass production and industrial series; for CFC (hard) this is the value for CFC-12, and for CFC (soft) it is the value for HCFC-22. The effect scores for the greenhouse effect were calculated per substance as follows (Houghton et al., 1995):

$$\text{Greenhouse effect (kg)} = \text{GWP 100} \times \text{air emissions (kg)} \quad (2.2)$$

## 2. Ozone layer depletion

Ozone depletion potential (ODP) values have been established primarily for hydrocarbons containing bromine, chlorine, or CFCs. Here too, one of the substances (CFC-11) has been adopted as a reference. As for the greenhouse effect, it has added value for CFCs (hard) and CFCs (soft). The ODP equivalents for these groups are again CFC-12 and HCFC-22. The effect score for ozone depletion is calculated as follows (World Meteorological Organization, 1991):

$$\text{Ozone layer depletion (kg)} = \text{ODP} \times \text{air emissions (kg)} \quad (2.3)$$

## 3. Human toxicity

An important feature is that human toxicity combines scores for emissions to air, water and soil. The following values have been established for most substances (Vermeire et al., 1991):

- Human toxicological classification value for air (HCA)
- Human toxicological classification value for water (HCW)

- Value of human toxicological classification for soil (HCS).

The CML 2 baseline has not included soil emissions because this program does not have an impact category for substances emitted to the ground. The number of characterizing factors of soil is very limited. In addition, it can be assumed that emissions that initially enter the soil will eventually appear in groundwater and can therefore be treated as emissions to water (Vermeire et al., 1991).

A number of grades have been added for groups to this class: metal ions and various hydrocarbon groups. Metal ions have been assigned the same value as iron. The hydrocarbon values are given in Table 2.7. An equivalent has also been chosen for most of the other undefined values; for example for chlorine, bromine equivalent values have been used (Vermeire et al., 1991).

**Table 2.7.** HCA/HCW, ECA and POCP values for hydrocarbons

Substance	Human toxicity Air	Equivalent		
		Human toxicity Water	Toxicity Water	Fog Air
CxHy	Isopropanol	Isopropanol	Crude oil	Aliphatic average
CxHy aliphatic	Isopropanol	Isopropanol	Crude oil	Aliphatic average
CxHy aromatic	Benzene	Benzene	Benzene	Aromatic average
CxHy chloro	1,2, dichloroethane	1,2, dichloroethane	1,2, dichloroethane	Chlorinated average
Polycyclic aromatic hydrocarbon (PAH)	Benzo(a)pyrene	Benzo(a)pyrene	Benzo(a)pyrene	Aromatic average

The human toxicity effect score was calculated as follows (Vermeire et al., 1991):

$$\text{Human toxicity (kg)} = (\text{HCA (kg.kg}^{-1}) \times \text{emissions to air (kg)} + \text{HCW (kg.kg}^{-1}) \times \text{emissions to water (kg)}) \quad (2.4)$$

#### 4. Ecotoxicity

Substances in these class are rated for toxicity to flora and fauna. The main substances are heavy metals. Values have been set for emissions to water and to soil, namely: Aquatic ecotoxicity (ECA) and Terrestrial ecotoxicity (ECT).

Only the ECA values were included in the CML 92 method because emissions to soil eventually appear in groundwater and are therefore included. A number of grades for the hydrocarbon group have been added to this class. The values for the hydrocarbons are shown in Table 2.7. An equivalent has been chosen for most of the other undefined values. The effect score for ecotoxicity was calculated as follows (Vermeire et al., 1991):

$$\text{Ecotoxicity (m}^3\text{)} = \text{ECA (m}^3\cdot\text{kg}^{-1}\text{)} \times \text{waterborne emissions (kg)} \quad (2.5)$$

#### 5. Photochemical oxidation

Photochemical ozone generation potential (POCP) indicates the potential capacity of volatile organic substances to produce ozone. Values have been published for various volatile organic substances. The value for ethene is set at 1. Values for most other substances are less than this. The POCP of these number-parameters such as alcohols, ketones, aldehydes and various hydrocarbon groups is the average of all the relevant substances in the CML list (1992). The values for the hydrocarbon groups are given in Table 2.7. NO<sub>x</sub> was removed in the CML 92 method. The effect score for smog was calculated as follows (UNECE, 1991):

$$\text{Fog (kg)} = \text{POCP} \times \text{air emission (kg)} \quad (2.6)$$

#### 6. Acidification

Acidification potential (AP) is expressed relative to the acidifying effect of SO<sub>2</sub>. Other known oxidizing agents are nitrogen oxides and ammonia. SO<sub>x</sub> has been added, with the same value as SO<sub>2</sub>. The acidification effect score was calculated as follows (Guinée, 2002):

$$\text{Acidification (kg)} = \text{AP} \times \text{air emissions (kg)} \quad (2.7)$$

#### 7. Eutrophication

The nitrification potential (NP) was set to 1 for phosphate (PO<sub>4</sub>). Other emissions also affect eutrophication, particularly nitrogen oxides and ammonium. The eutrophication effect score was calculated as follows (Guinée, 2002):

$$\text{Eutrophication (kg)} = \text{NP} \times \text{air emissions (kg)} \quad (2.8)$$

## 8. Abiotic depletion

Abiotic resources are non-living natural resources, such as iron ore or crude oil. Efficient use of these resources is one of the most important sustainability criteria. Most abiotic resources are non-renewable (except, for example, wind). In 1992 according to Heijungs (Heijungs et al., 1992) for a given resource  $i$ , abiotic depletion was defined as the ratio between the amount of extracted resource ( $mi$ ) and the reserves recoverable from that source ( $Mi$ ).

$$\text{Abiotic depletion} = \sum_i \frac{mi}{Mi} \quad (2.9)$$

The units used for extraction and backup can thus be freely chosen, as long as they are consistent for a given source. Ore is usually expressed in kg and natural gas in  $\text{m}^3$ , although MJ can be used as an alternative. Heijungs observes that this is a simplified method and which should eventually be expanded to include extraction rates, expressed in  $\text{kg}/\text{year}$  or  $\text{m}^3/\text{year}$ .

## 2.12 Energy, Cumulative Energy Demand, and Energy Balance

### 2.12.1 Energy

In physics, energy is a unit of capacity to accomplish work or work. There are different types of energy, including kinetic, thermal, electrical, chemical, nuclear, and others. According to the rule of conservation of energy, energy may be altered in form but cannot be generated or destroyed. In the International System of Units (SI), the joule is the amount of energy delivered to an item by pushing it one metre away against a force of one newton. Every kind of energy is tied to motion; for example, when an item moves, it possesses kinetic energy. Even while at rest, a tensioned device, such as an arc or spring, has the ability to move (Sutikno et al., 2020).

Because of its configuration, it also carries potential energy. Nuclear energy is also potential energy since it originates from the arrangement of subatomic particles in the atomic nucleus. Kinetic energy of a moving object, potential energy stored by an object's position in a gravitational, electric, or magnetic force field, elastic energy stored by stretching a solid object, chemical energy released when fuel burns, radiant energy carried by light, and heat energy due to an object's temperature are all examples of common types of energy (Sutikno et al., 2020).

Mass and energy are inextricably linked. Because of mass-energy equivalence, any object with mass at rest is referred to as rest mass. The rest mass has an equivalent quantity of energy known as rest energy, and every additional energy in whatever form that an item gets on top of that rest energy increases the object's total mass by the same amount as it raises its total energy. For example, after heating an item, the increase in energy may be measured in principle as a modest increase in mass on a fairly sensitive scale (Sutikno et al., 2020).

### 2.12.2 Cumulative energy demand

Cumulative energy demand (CED) displays the outcomes of energy demand in six energy source categories: renewable water, wind, nonrenewable biomass, renewable biomass, nonrenewable fossils, diesel, nonrenewable nuclear, and renewable geothermal. The cumulative energy demand effect assessment approach used in Ecoinvent is shown in Table 2.8. (Frischknecht et al., 2007).

**Table 2.8.** Energy sources of cumulative energy demand

Category	Sub-category	Energy sources
Non-renewable resources	Primary forest	Biomass and wood from primary forest
	Fossil	Natural gas, lignite, peat, gas coal mining, hard coal, crude oil
	Nuclear	Uranium
Renewable resources	Solar energy	Solar energy (used for electricity and heat)
	Biomass	Wood biomass, food products, agricultural biomass, straw
	Wind	Wind energy
	Geothermal	Geothermal energy from geothermal (shallow: 100-300m)
	Water	Reservoir hydropower and river hydropower



### 1. Fossil energy resources

Peat is classified as a fossil resource, even if it is derived from biomass, because it is not renewable within a reasonable time frame. Sulphur and other material resources having a heating value (e.g., sulphidic ores) are not considered energy resources since their energy content is often not exploited. Economic restrictions constrain the production of fossil energy supplies. This is why some reserves in an oil field or a coal mine are kept in place. When room-and-pillar mining is used in underground coal mining, between 30 and 55 % of the mineable hard coal is left in the mine to sustain the open coal seams (Dones et al., 2007). Because production efforts rise significantly when peak oil is achieved, making it uneconomic to continue production, oil fields will be abandoned before all oil is taken. The remaining resources in the earth are still available and may be extracted in the future when production becomes profitable (again). As a result, these resources are not lost. As a result, these resources are not lost. The quantity of fossil energy resources retrieved from the earth, such biomass, is termed the amount harvested (Frischknecht et al., 2015).

### 2. Nuclear energy resources

The quantity of uranium taken from mines is tracked in the same way that fossil energy resources are. The quantity of fissile uranium removed that ends up in depleted uranium (enrichment phase) and wasted fuel is not currently accounted for since it is still deemed accessible for energy conversion. This reasoning, however, might be contested. Extraction of fissile uranium from depleted uranium or wasted fuel is uneconomic and so deemed lost. Including these losses (one-third lost in enrichment and one-sixth lost in used fuel) in nuclear energy accounting would increase the energy value of uranium by nearly 50% (Frischknecht et al., 2015).

### 3. Biomass energy resources

The biomass calculation (wood, food items, agricultural by-products, etc.) is based on the highest heating value of the biomass product at the time of harvest (not include residues such as roots that stay in the forest or field). The higher heating value of various wood kinds and agricultural products is inventoried in the inventory as "Energy, gross calorific value, in biomass." Furthermore, wood resources are considered an inventory item. The application of a CED factor for wood resources is prohibited since it would result in duplicate counting (Frischknecht et al., 2007).

#### 4. Wind, solar, and geothermal energy resources

The rotating energy of the turbine blades transferred to the gearbox equals the kinetic energy transformed (harvested) by a wind power plant. The efficiency of the blades in converting kinetic wind energy to rotation energy is not considered (Burger & Bauer, 2007). Solar energy transformed (harvested) by photovoltaic power plants equals photovoltaic electricity produced and delivered to the inverter. The thermal energy transferred to the hot water storage equals the solar energy produced (harvested) by a solar collector. The effectiveness of the panel and collector in converting solar energy to electricity and heat is not considered (Frischknecht et al., 2007). The quantity of energy transferred to the heat pump is equal to the amount of geothermal energy transformed (harvested) via brine-water heat exchangers. Deep geothermal plants (e.g., < 1000 m) are often intended to over-exploit the available heat reservoir and actually cool down the affected region for a lengthy period of time (Frischknecht et al., 2007).

#### 5. Water energy sources

The rotation energy transferred to the turbine for hydro power generation is utilised as a characterization factor in hydro energy. The rotation energy matches the hydroelectric reservoir's converted potential energy. If the pumping energy originates from a non-hydro source, hydro energy from pumping stored hydro power is omitted from the inventory (Frischknecht et al., 2007).

### 2.12.3 Energy balance

The value of net energy balance (NEB) and net energy ratio (NER) may be used to determine energy balance analysis. NEB is derived by subtracting the output energy from the biodiesel synthesis process ( $NEB = E_{out} - E_{in}$ ). The output energy divided by the input energy from the biodiesel synthesis process is used to compute NER ( $NER = E_{out} / E_{in}$ ). The results of NEB and NER computations might be positive (+) or negative (-). The indicators of success for the study of energy balance analysis so that the biodiesel production process is feasible to operate are positive NEB and NER (Nguyen et al., 2007; Prueksakorn et al., 2010).

The energy balance in the biodiesel production life cycle is often analysed using four parameters: net energy value (NEV), net renewable energy values (NRnEV), net energy ratio (NER), and renewability. The formula for computing these four parameters is shown in Table 2.9 (Silalertruksa & Gheewala, 2012).

**Table 2.9.** The parameters of energy balance

Parameter	Formula
NEV	Energy content of biodiesel (and its co-products) - Net energy input
NRnEV	Energy content of biodiesel (and its co-products) - Fossil energy inputs
NER	Net energy outputs / Net energy inputs
Renewability	Net energy outputs/ Net fossil energy inputs

The energy input value is the same as the cumulative energy demand value, namely non-renewable fossils, non-renewable nuclear, renewable water, renewable biomass, wind, solar, and geothermal. The energy output value equals the energy content of biodiesel (and its co-products), which includes multi-feedstock biodiesel, glycerol, meal, palm kernel, shells, EFB, and biogas recovered from POME (Frischknecht et al., 2007; Silalertruksa & Gheewala, 2012).

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