Chapter 1

General Introduction

1.1 Background

In 2018, Indonesia's total primary energy output, which includes oil, natural gas, coal, and renewable energy, reached 411.6 million tonnes of oil equivalent (Mtoe). The export of around 64 percent of total output, or 261.4 Mtoe, was dominated by coal and liquefied natural gas (LNG) (Suharyati et al., 2019). However, Indonesia continues to import energy, particularly crude oil and petroleum products, totaling 43.2 Mtoe, to fulfill the demands of its industrial sector. In 2018, Indonesia's overall energy consumption (excluding traditional biomass) was roughly 114 Mtoe, with 40% going to transportation, 36% to industry, 16% to homes, 6% to the commercial sector, and 2% to other sectors. Over the previous decade, Indonesian oil output has declined, from 48.44 Mtoe in 2009 to roughly 39.62 Mtoe in 2018. (Suharyati et al., 2019). In output, owing mostly to the age of the main oil wells and a scarcity of new wells.

The lower output of fossil energy, particularly petroleum, and the worldwide commitment to reducing greenhouse gas emissions have motivated the Indonesian government to continue to encourage the role of new and renewable energy in ensuring energy security and independence (Suharyati et al., 2019). According to Indonesian Government Regulation No. 79 of 2014 on National Energy Policy, the aim for new and renewable energy in 2025 is at least 23% and 31% in 2050. (Government Regulation of the Republic of Indonesia Number 79 of 2014 Concerning National Energy Policy, 2014). These goals are based on a low-carbon, long-term development scenario between 2025 and 2050. (Suharyati et al., 2019). One of the policy mandates is the 20% biofuel mix ratio (B20) in the transportation sector. Indonesia has significant potential for sufficient renewable energy adoption to realize its energy mix targets.

The use of renewable energy in the transportation sector, especially biodiesel, began to grow rapidly in line with the implementation of biofuel policies. In 2018, Indonesia's biodiesel production, exports and domestic demand were 4706, 1512, and 2618 kilo liters (kL), respectively. The Indonesian government is confident about future advancements in biodiesel use (Suharyati et al., 2019). In Indonesia, palm oil is primarily used as a raw ingredient in the production of biodiesel. Palm oil has a tremendous potential for supporting bioenergy development initiatives, namely biodiesel. In 2016, around 3.4 million tonnes of crude palm oil (CPO) were utilised for biodiesel production (Wright & Rahmanulloh, 2017). Indonesia is the world's largest palm oil producer, accounting for half of worldwide CPO output (FAOStat, 2017). The annual global production of palm oil (palm pulp) is 39 million tonnes. Indonesia (17.1 million t) and Malaysia (16.6 million t) are the leading producers (Agrianual, 2008). The potential of palm oil as a food source and as the main raw material for biodiesel in Indonesia is also very large (Wright & Rahmanulloh, 2015).

Life Cycle Assessment (LCA) is a mechanism for analysing and calculating the total environmental impact of a product at each stage of its life cycle, including raw material preparation, production processes, sales and transportation, and product disposal (ISO 14040, 2006). Although biodiesel is claimed to be a renewable energy, the biodiesel production process uses chemicals and non-renewable resources, which can be an environmental burden. The use of urea produces N_2O (greenhouse gas) and therefore will have an impact on the environment (Silalertruksa & Gheewala, 2012; Siregar et al., 2015)

Oil palm biodiesel production in Indonesia still faces a degree of uncertainty due to the expansion of oil palm plantations, stimulating debate about the environmental consequences. Land use change from conversion of forest land and agricultural land to oil palm plantations can have further environmental implications, such as greenhouse gas (GHG) emissions from changes in soil carbon stocks and biomass, forest fires, emissions of air pollutants, loss of biodiversity, and loss of animals, plants, and species in forest ecosystems (Bessou et al., 2014; Danielsen et al., 2009; Fayle et al., 2010; Germer & Sauerborn, 2008; Wicke et al., 2011).

Therefore, an LCA study should be conducted to evaluate the potential environmental impacts associated with the life cycle of oil palm biodiesel production.

There have been a number of studies reporting on the life cycle of palm oil production (Achten et al., 2010; Papong et al., 2010; Schmidt, 2010; De Souza et al., 2010; Stichnothe & Schuchardt, 2011; Choo et al., 2011; Hassan et al., al., 2011; Siangjaeo et al., 2011; Hansen et al., 2012; Harsono et al., 2012; Kaewmai et al., 2012; Queiroz et al., 2012; Patthanaissaranukool et al., 2013; Castanheira et al., 2014; Rodrigues et al., 2014; Soraya et al., 2014; Siregar et al., 2015). However, the majority focus on GHG emissions and energy requirements (Papong et al., 2010; De Souza et al., 2010; Choo et al., 2011; Hassan et al., 2011; Siangjaeo et al., 2011; Hansen et al., 2012; Harsono et al., 2012; Kaewmai et al., 2012; Queiroz et al., 2012; Patthanaissaranukool et al., 2013; Castanheira et al., 2014; Rodrigues et al., 2014), and only a few LCAs addressing broader environmental impacts (Achten et al., 2010; Papong et al., 2010; Schmidt, 2010; Stichnothe & Schuchardt, 2011; Soraya et al., 2014; Siregar et al., 2015). Life cycle studies that contribute to carbon emissions from land use change (LUC) (Hassan et al., 2011; Siangjaeo et al., 2011; Harsono et al., 2012; Silalertruksa & Gheewala, 2012; De Souza et al., 2012; Rodrigues et al., 2014) show that this has a significant effect on the intensity of greenhouse gas (GHG) emissions from palm oil biodiesel production. However, other results reported on the estimation of the impact of various expansions of oil palm area broadly, indicate that this is still a topic that still needs to be discussed (Lechon et al., 2011; Castanheira et al., 2014). The environmental impact of palm oil biodiesel also depends on land use practices, residue disposal practices, biogas management, and palm oil mill effluent (POME) treatment (Achten et al., 2010; Stichnothe & Schuchardt, 2010; Choo et al., 2011; Lam & Lee, 2011; Hansen et al., 2012; Harsono et al., 2012; Queiroz et al., 2012; Patthanaissaranukool et al., 2013). Calculation of nitrogen (nitro oxide (N_2O), nitrogen oxide (NO_x), and ammonia (NH_3)), and phosphorus emissions from oil palm plantations are also important aspects of palm oil biodiesel LCA. This calculation affects the results of several environmental impacts, such as GHG intensity, eutrophication, and acidification (Achten et al., 2010; De Souza et al., 2010; Choo et al., 2011; Reijnders & Huijbregts, 2011; Harsono et al., 2012).

Dependence on one palm oil raw material for biodiesel production can cause problems, namely the conversion of forest land into oil palm plantations which has an impact on the environment. Tens of thousands of hectares of forest spread across the provinces of Riau and Kalimantan – Indonesia have been converted into oil palm plantations, resulting in the loss of crop varieties and animal habitats. Then, oil palm is a type of crop that absorbs a lot of water and soil nutrients which slowly reduces the level of soil fertility. Water consumption and scarcity are important issues for oil palm cultivation due to high water requirements for effective yields (Gheewala et al., 2014). Furthermore, the effective storage of biodiesel has also proven to be a challenge, with the Indonesian government having invested billions of rupiah (IDR) to address this challenge (Hidayat, 2016). The effect of storage on biodiesel quality is important due to biodiesel must go through a storage process before reaching its destination, regardless of type.

If we look at the natural potential in Indonesia, there are many other vegetable oil potentials that can be used as raw materials for biodiesel production, including soybean oil, canola oil, and sunflower oil. Soybean, sunflower, and canola plants can be grown in Indonesia, which has a tropical climate with year-round sunshine. Biodiesel can also be produced from used cooking oil (Yusuff et al., 2018; Ani et al., 2018). In the society, used cooking oil is often discharged into the environment without being processed first. Utilising used cooking oil as raw material for biodiesel production is a good effort so that used cooking oil does not pollute the environment (Hadiyanto et al., 2018; Hadiyanto et al., 2020). National consumption of palm cooking oil reached 16.2 million kilo liters (KL). From this figure, the average used cooking oil produced is in the range of 40-60% or in the range of 6.46 - 9.72 million KL. Unfortunately, the used cooking oil that can be collected in Indonesia has only reached 3 million KL or only 18.5% of the total national consumption of palm cooking oil. The study found that only a small proportion of used cooking oil in Indonesia is used as biodiesel. Of the 3 million KL that was collected, only about 570 KL was converted for biodiesel and other needs, while the remaining 2.4 million kilo liters were used for recycled cooking oil and exports. The use of used cooking oil for biodiesel is a good option as part of increasing the circular economy, namely recycling the use of resources to continue to produce economic benefits while reducing environmental impacts (Ministry of Energy and Mineral Resources of The Republic of Indonesia, 2020).

Previous researchers have studied biodiesel production from multiple feedstocks due to biodiesel from several single feedstocks such as jatropha, pongamia, jatropha, beef tallow, sunflower, peanut, and corn showed poor quality (Gomes Souza et al., 2021). Palm oil biodiesel has poor cold flow properties, namely cloud point (16°C), pour point (15°C), and cold filter blockage (12°C) (Atabani et al., 2012). The use of blended oil feedstock helps reduce the costs incurred in using different additives to improve the oxidation stability and cold flow properties of the biodiesel produced (Kumar et al., 2021). Therefore, preparing a blend of different oils that come from abundant resources (e.g., palm oil, canola oil, soybean oil, sunflower oil) mixed with a low-cost and poor-quality oil (e.g., used cooking oil) can help provide a blended oil optimum performance with improved fuel properties.

According to previous research, biodiesel may be produced utilising many mixed feedstocks, which is referred to as multi-feedstock biodiesel. Two mixes of raw materials, particularly palm oil and coconut oil, may be used to produce multi-feedstock biodiesel (Widayat et al., 2015). Producing multi-feedstock biodiesel requires three combinations of raw materials: soybean oil, canola oil, and fatty oil (Flood et al., 2016). Five mixes of raw materials, including nyamplung oil, castor oil, palm oil, and leftover cooking oil, have been utilised effectively to produce multi-feedstock biodiesel (Hadiyanto et al., 2020). Blending oils for biodiesel production increases the chances that large-scale biodiesel production will be sustainable, of higher quality, and able to fulfil the needs of large-scale industrial and transportation sectors (Manaf et al., 2019; Kumar et al., 2021). However, no prior industrial-scale studies have simulated and estimated the LCA of the multi-feed biodiesel production process. The usage of materials and energy may potentially alter the energy balance of biodiesel production from several feedstocks. To estimate the value of the energy balance, the energy output of multi-feedstock biodiesel must be compared to the energy inputs required to produce it (Silalertruksa & Gheewala, 2012; Wahyono et al., 2019). Material and energy inputs as well as emission outputs in the production of multi-feedstock biodiesel have the potential to impact the environment in the form of global warming, acidification, eutrophication, and ecotoxicity. These environmental impacts may lead to environmental damage, including to human health, ecosystems, and resources, at the endpoint (Goedkoop et al., 2013; Rashedi & Khanam, 2020). An LCA study that assesses and analyses energy balance, environmental impacts, and environmental damages at the end-point of the biodiesel production life cycle at industrial scale needs to be done. The findings of the LCA study on the life cycle of multi-feedstock biodiesel production will be compared to the life cycle of palm oil biodiesel production, the major biodiesel in Indonesia at present. In the end, it will be analysed whether multi-feedstock biodiesel is preferable to palm oil biodiesel in Indonesia from energy and environmental prespective, or vice versa.

1.2 Formulation of the Problems

In 2016, Indonesia produced 3.6 million kL of biodiesel. The objective for Indonesia in 2025 is 8.7 million kL. The Indonesian government has committed billions of Indonesian rupiah (IDR) in an effort to overcome the challenge of biodiesel storage (Hidayat, 2016). The impact of storage on the quality of biodiesel is significant since all types of biodiesel must undergo a storage procedure before reaching their final destination. During storage, biodiesel is oxidised and hydrolyzed, leading to a rise in acid value (Jain & Sharma, 2012), total glycerol (Silviana & Buchori, 2015), peroxide value, and decreasing methyl ester content (Jain & Sharma, 2010).

In Indonesia, the environmental impacts of palm oil biodiesel production raised controversy once oil palm plantations increased. Changes in land use resulting from the conversion of forest land and agricultural land to oil palm plantations can have additional environmental consequences, including greenhouse gas (GHG) emissions from changes in soil carbon stocks and biomass, forest fires, air pollutant emissions, biodiversity losses, and extinctions of animals, plants, and species in forest ecosystems (Fayle et al., 2010; Wicke et al., 2011; Bessou et al., 2014). Therefore, a life cycle assessment (LCA) must be done to assess the potential environmental impact of palm oil biodiesel production.

Biodiesel production from a blend of several vegetable oils and used cooking oil might be advantageous for nations like Indonesia with a growing need for biodiesel (Hadiyanto et al., 2018; Hadiyanto et al., 2020). Multi-feedstock biodiesel is the term for biodiesel produced from multiple source feedstocks (Flood et al., 2016; Hadiyanto et al., 2020). Researchers have investigated biodiesel production from several feedstocks since biodiesel from certain single feedstocks, including jatropha, pongamia, castor, bovine tallow, sunflower, peanut, and corn, exhibited low quality (Gomes Souza et al., 2021). Poor cold flow qualities of cloud point (16°C), pour point (15°C), and cold filter clogging (12°C) characterise palm oil biodiesel (Atabani et al., 2012). The utilisation of mixed oil feedstock reduces the expense of using various additives to increase the biodiesel's oxidation stability and cold flow qualities (Kumar et al., 2021).

Previous research indicates that biodiesel may be created utilising multiple feedstocks (Flood et al., 2016; Hadiyanto et al., 2020). Therefore, blending oils for biodiesel production increases the likelihood that large-scale biodiesel production will be sustainable and of higher quality, and may satisfy the large-scale industrial and transport demand (Manaf et al., 2019; Kumar et al., 2021). However, no prior research has simulated and estimated the LCA of the multi-feedstock biodiesel production process. This research utilises LCA to evaluate the environmental impact of industrial-scale production of biodiesel from multiple feedstocks.

Biodiesel is a renewable energy that may be substituted for diesel. In the biodiesel production life cycle, environmental impact and energy balance are two variables to consider. Although biodiesel is a renewable energy source, its production is still dependent on fossil fuels, which are nonrenewable (Pleanjai & Gheewala, 2009; Wahyono et al., 2019). The use of fossil energy in biodiesel production has a substantial influence on the environment, especially in the production of palm oil biodiesel. Fertiliser, methanol, and transportation are typical applications of fossil energy (Pleanjai & Gheewala, 2009; Silalertruksa & Gheewala, 2012; Wahyono et al., 2020). It is thus essential to evaluate the energy balance of palm oil biodiesel production. Similarly, understanding the energy balance of multi-feedstock biodiesel production is essential for multi-feedstock biodiesel production. This is to determine if the biodiesel multi-feedstock plant can be operated feasibly from an energy perspective.

Environmental impacts such as global warming, acidification, eutrophication, human toxicity, ecotoxicity, and abiotic depletion have been the subject of prior research on multi-feedstock biodiesel production (Wahyono et al., 2022). These impacts will continue to contribute to environmental damage at the endpoint, including damage to human health, biodiversity, and resource availability. Human health is damaged by global warming, photochemical oxidant production, and human toxicity. The diversity of ecosystems is damaged by climate change, acidification, eutrophication, and ecotoxicity. Metal depletion and fossil depletion contribute to damage to resource availability (Goedkoop et al., 2013; Rashedi & Khanam, 2020; Wahyono et al., 2020). It is essential to comprehend the environmental performance of multi-feedstock biodiesel production at the end-point. The above problems may be expressed as follows:

1) The decline in biodiesel quality is due to oxidation and hydrolysis that occurs during storage.
2) Biodiesel produced from a single feedstock exhibited poor oxidation stability and poor cold flow properties.
3) Indonesia has abundant potential of used cooking oil and not all of it has been managed as feedstock for biodiesel production.
4) It is essential, to evaluate the energy balance of multi-feedstock biodiesel production, to determine whether or not the multi-feedstock biodiesel plant is viable to operate.
5) The biodiesel production life cycle has an impact on the environment as a result of material and energy inputs and emissions output

1.3 Research Question

Based on the formulation of the issue, the following research questions may be formed:

1) How does long-term storage influence the quality of palm oil biodiesel?
2) How does the life cycle of palm oil biodiesel production affect the environment?
3) How is the quality of biodiesel produced from palm oil, used cooking oil, soybean oil, canola oil, and sunflower oil?
4) Is the energy balance of the life cycle of multi-feedstock biodiesel production better to that of palm oil biodiesel production?
5) Is the multi-feedstock biodiesel production life cycle have a lower environmental impact than palm oil biodiesel alone?

6) Is the multi-feedstock biodiesel production life cycle cause less environmental damage than palm oil biodiesel alone?

1.4 Research Originality

The following features differentiate this study from previous research:

1) No prior study has been conducted on the production and quality analysis of biodiesel produced from a mixture of palm oil, used cooking oil, soybean oil, canola oil, and sunflower oil.
2) The energy balance analysis of the multi-feedstock biodiesel production life cycle has not been studied before.
3) The environmental impact of the biodiesel multi-feedstock production life cycle has not been studied before.
4) No prior research has been conducted on the environmental damage of the multi-feedstock biodiesel production life cycle.

Table 1.1 depicts the search for research results used to evaluate the originality of this study and as a research guide.

Table 1.1. The findings of studies connected to the originality of the study

No.	Title, name of researcher, and year	Research objectives	Research methods	Research results
1.	A life cycle assessment comparison between centralized and decentralized biodiesel production from raw sunflower oil and waste cooking oils Loreto Iglesias, Adriana Laca, Mónica Herrero, Mario Díaz, 2012 (Iglesias et al., 2012)	This research attempts to evaluate the environmental effect that the degree of decentralization of the number of production facilities in a given region has on the production of biodiesel from crude sunflower oil or used cooking oil.	This study examines the LCA of the biodiesel production process from crude sunflower oil and spent cooking oil using a single feedstock. This research use Eco-indicator 99 (H) V2.05/Europe EI 99 H/A as a tool for assessing the life cycle effect. The result of the calculation of the impact category for Eco-indicator 99 (H) V2.05/ Europe EI 99 H/A is damage to human health, which includes the following impact categories: carcinogenesis, organic respiratory effects, inorganic respiratory effects, climate change, ionizing radiation and ozone depletion. Ecotoxicity, acidification/eutrophication, and land use all have negative effects on the quality of an ecosystem. Degradation of resources, such as minerals and fossil fuels.	The results indicate that the degree of centralized optimization differs for each of the investigated cases. In general, centralized production is better for the environment in small regions, although decentralization is preferable as the area develops.
2.	Life Cycle Assessment (LCA) of the biofuel production process from sunflower oil, rapeseed oil and soybean oil J.F. Sanz Requena, A.C Guimaraes, S. Quirós Alpera, E. Relea Gangas, S. Hernandez Navarro, L.M. Navas Gracia, J. Martin Gil, H. Fresneda Cuesta, 2010 (Requena et al., 2010)	The purpose of this research is to examine the environmental effect of biofuel generation from sunflower, rapeseed, and soybean oil. The environmental effect of each biofuel production is determined using a life cycle assessment (LCA) technique.	This study examines the LCA of the biodiesel production process using sunflower oil, rapeseed oil, and soybean oil as a single feedstock. This research use Eco-indicator 99 (H) V2.05/Europe EI 99 H/A as a tool for assessing the life cycle effect.	The data indicated that seed production was the primary source of contamination. The authors also discovered a substantial effect on the drying and seed preparation processes, as well as the crude soybean oil extraction process. In addition, the LCA analysis demonstrates that the cultivation of rapeseed and sunflower contributes positively to climate change.
3.	Comparative life cycle assessment of alternative strategies for energy recovery from used cooking oil	This study aims to analyse four of the conventional and innovative technologies, characterized by different types and amounts of chemicals used, consumption and yield of electricity and	This research is about LCA in single feedstock biodiesel production process from used cooking oil. This study uses CML-IA as a life cycle impact assessment method. CML-IA has the result of the calculation of the impact category, namely global warming potential (GWP).	When product substitution and co-products are included, the savings realized from replacing traditional diesel production with biodiesel are much more than the impacts averted for electricity and heat in the case of cogeneration. Savings from

No.	Title, name of researcher, and year	Research objectives	Research methods	Research results
	Lidia Lombardi, Barbara Mendecka, Ennio Carnevale, 2017 (Lombardi et al., 2017)	heat. The author conducts a systematic evaluation of environmental benefits and drawbacks by applying a life cycle assessment (LCA) analysis to compare alternatives.		employing UCO in the biodiesel production process range from 41.6 to 54.6 GJex per tUCO for CExC and GWP, respectively, and from 2270 to 2860 kg CO_2eq per tUCO for CExC and GWP. Sensitivity and uncertainty analysis are given special attention. Overall, there was a considerable level of variability in the ultimate yield due to the influence of the method, particularly for the supercritical methanol procedure. For avoided impacts, low uncertainty values were examined. Taking into account the unknown impact character, cogeneration scenario, and NaOH-catalyzed process from biodiesel production, the most suited option in terms of process impact and prevent impacts is found.
4.	Incorporating uncertainty in the life cycle assessment of biodiesel from waste cooking oil addressing different collection systems Carla Caldeira, João Queirós, Arash Noshadravan, Fausto Freire, 2016 (Caldeira et al., 2016)	This research intends to investigate the LCA of the two elements that most contribute to the observed variance, namely the effectiveness of WCO collection and the features of the collection system (such as sector, type of collection and population density) (such as sector, type of collection and population density).	This research is about the life-cycle evaluation of a single feedstock biodiesel synthesis process utilising waste cooking oil. The life cycle impact assessment technique ReCiPe is employed in this research. Climate change terrestrial acidification (TA), ozone depletion (OD), photochemical oxidant production (POF), and fossil depletion are the impact categories estimated by ReCiPe (FD).	The findings suggest that WCO collection cannot be overlooked or simplified when analysing the total environmental performance of biodiesel produced from WCO.
5.	Life cycle assessment (LCA) and exergetic life cycle assessment (ELCA) of the production of biodiesel from used cooking oil (UCO) L. Talens Peiro´, L Lombardi, G. Villalba Me´ ndez, X. Gabarrell i Durany, 2010 (Peiró et al., 2010)	This research is to evaluate the life cycle of biodiesel produced from spent cooking oil (UCO). The UCO life cycle consists of four stages: collection, pretreatment, delivery, and transestification.	This study focuses on the LCA of the biodiesel synthesis process using spent cooking oil as a single feedstock. This research used CML 2 baseline 2000 as a tool for assessing the life cycle effect. CML 2 baseline 2000 impact calculation results are as follows: abiotic depletion (AD), ozone layer depletion (ODP), global warming potential (GWP), human toxicity (HT), fresh water aquatic ecotoxicity (FWAE), marine aquatic ecotoxicity (MAE), terrestrial ecotoxicity (TE), photochemical oxidation (PO), acidification (A), and eutrophication (E).	The data indicated that the transesterification process was responsible for 68% of the entire environmental effect. The primary sources of exergy are uranium and natural gas. If the objectives of the Spanish Renewable Energy Plan are realized, the energy inputs for biodiesel production in the existing system would be decreased by 8 %, and the environmental effect and energy inputs would be reduced by 36 % in 2010.

No.	Title, name of researcher, and year	Research objectives	Research methods	Research results
6.	Life Cycle Assessment of Biodiesel Production from Palm Oil in Indonesia Delfi F Soraya, Shabbir H Gheewala, Sébastien Bonnet, Chakrit Tongurai, 2014 (Soraya et al., 2014)	Using a life cycle assessment technique, this research sought to determine the environmental effect of biodiesel production from palm oil in Indonesia..	This study focuses on the LCA of the palm oil biodiesel production process using a single feedstock. This research used CML 2 baseline 2000 as a tool for assessing the life cycle effect.	The use of fertilisers and pesticides during the planting phase contributed the most to the potential for global warming, accounting for 58 percent of the total, according to the conclusions of this research. In the mill, palm oil byproducts may be used to produce power. Due to its dependence on coal-fired power plants, electricity has a considerable impact on the environment. The biodiesel production process adds greatly to photochemical oxidation's negative effects. Transportation has a significant influence on the environment.
7.	A life cycle assessment of biodiesel production from winter rape grown in Southern Europe Carles M Gasol, Jordi Salvia, Joan Serra, Assumpcio Anto, Eva Sevigne, Joan Rieradevall, Xavier Gabarrell, 2012 (Gasol et al., 2012)	This research intends to integrate physical characteristics such as grain production and agro-climatic conditions with environmental analysis (LCA) to estimate the Mediterranean agro-climatic zones that may be planted for non-consumable food.	This research examines at LCA in a single feedstock biodiesel production process utilising rapeseed oil. As a life cycle impact evaluation technique, this research employed CML 2 baseline 2000.	The findings obtained in terms of environmental performance, biodiesel systems have less effect than diesel in the three categories Abiotic Depletion (AD), Photochemical Oxidation (PO), and Global Warming Potential (GWP) (GWP). When compared to diesel, the anticipated reduced impact in the GWP category reaches a minimum of 1.76 kg CO_2 eq per kilogram of biodiesel at emission from the use phase. This study also reveals that the agro-climates known as "e," "b," and "d" that promise grain yield for biodiesel commercialization are more than 2000 kg ha-1 when compared to B. napus energy crops for local and regional energy production and strategy distribution.
8.	Life cycle assessment of hydrogenated biodiesel production from waste cooking oil using the catalytic cracking and hydrogenation method	This study aims to determine the environmental benefits (global warming, consumption of fossil fuels, urban air pollution, and acidification) of hydrogenated biodiesel (HBD) produced from used cooking oil through catalytic cracking and hydrogenation, compared to fossil fuels.	This research is about LCA in single feedstock biodiesel production process from used cooking oil. This study uses LIME as a life cycle impact assessment method. LIME has calculated the results of impact categories: fossil fuel consumption, global warming, urban area air pollution and acidification.	The results show that if diesel vehicles comply with Japan's commonly used long-term gas emission standards in the future, the benefits of biodiesel fuel (BDF) type fatty acid methyl esters (FAME) will be relatively limited. Furthermore, the scenario that introduces HBD is most effective in reducing the total environmental impact, which

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	Junya Yano, Tatsuki Aoki, Kazuo Nakamura, Kazuo Yamada, Shin-ichi Sakai, 2015 (Yano et al., 2015)			means that the shift from FAME-type BDF to HBD will be more profitable.
9.	A Comparison of Life Cycle Assessment on Oil Palm Elaeis guineensis Jacq.) and Physic nut (Jatropha curcas Linn.) as Feedstock for Biodiesel Production in Indonesia Kiman Siregar, Armansyah H Tambunan, Abdul K Irwanto, Soni S Wirawan, Tetsuya Araki, 2015 (Siregar et al., 2015)	This research seeks to quantify and compare the LCA of palm oil and castor oil biodiesel generation.	This study focuses on LCA in the palm oil and castor oil single-feedstock biodiesel production process. This research employs the IPCC 2007 methodology for life cycle impact assessment. IPCC 2007 contains the calculation result for the impact category, namely global warming potential (GWP).	The GWP value of biodiesel produced from palm oil is greater than that of biodiesel produced from castor oil. The usage of fertilisers and plant protection contributed the most to pollution, namely 50.46 % for oil palm and 33.51 % for jatropha.
10.	Environmental life-cycle assessment of rapeseed-based biodiesel: Alternative cultivation systems and locations João Malça, António Coelho, Fausto Freire, 2014 (Malça et al., 2014)	This research intends to evaluate the environmental performance of biodiesel production from rapeseed, as well as explore alternative geographic sites and farming methods for rapeseed (in Spain, France, Germany and Canada).	This study focuses on LCA in the synthesis of biodiesel from rapeseed oil using a single feedstock. This research use the CML 2001 life cycle assessment technique. CML 2001 has estimated findings for the following categories of impact: abiotic depletion, global warming, acidification, and eutrophication.	Rapeseed cultivation contributed the most to all environmental impact categories investigated, with values ranging from 40 percent (abiotic depletion, Germany) to 98 percent (eutrophication, United States) (eutrophication, Spain). The largest factors to the environmental impact of agriculture are the use of fertiliser and the soil emissions that result from it. Changes in soil carbon induced by diverse agricultural systems are crucial for understanding the influence of biodiesel derived from rapeseed on global warming. The use of fossil methanol in biodiesel synthesis has a substantial impact on abiotic depletion, but the use of heavy fuel oils in transoceanic transport is a large contributor to acidification.

No.	Title, name of researcher, and year	Research objectives	Research methods	Research results
11.	Life cycle assessment of sunflower and rapeseed as energy crops under Chilean conditions Alfredo Iriarte, Joan Rieradevall, Xavier Gabarrell, 2010 (Iriarte et al., 2010)	This research aims to apply a cradle-to-farm life cycle assessment (LCA) to analyse the environmental effect and energy and water requirements of radish (Brassica napus L.) and sunflower (Helianthus annuus L.) in Chile, as prospective oleaginous crops for first-generation biodiesel production.	This study examines the LCA of the sunflower oil and rapeseed oil biodiesel production process from a single feedstock. This research utilises the CML 2 baseline 2001 to measure the life cycle impacts. CML 2 baseline 2001 has calculated the following impact categories: abiotic depletion potential, acidification potential, eutrophication potential, freshwater aquatic ecotoxicity potential, global warming potential, human toxicity potential, marine aquatic ecotoxicity potential, ozone layer depletion potential, photochemical ozone creation potential, radioactive radiation, and terrestrial ecotoxicity potential (TEP).	Compared to sunflower, the environmental performance of rapeseed cultivation was superior in nine of the eleven examined impact categories, and its water usage was lower. Rapeseed has an energy requirement of 4,9 GJ/t of seed, which is 30 percent less than sunflower. Mineral fertilisers have the greatest influence on the environment for both crops. The research of the fertiliser's life cycle reveals that the extraction and manufacture of raw materials is a crucial step. Evaluation of alternative kinds of fertilization should be the primary focus of efforts to lessen the environmental effect and energy demands of the two crops. In addition, low-impact herbicides should be examined, seed yields should be raised, and growing procedures should be adjusted, particularly for sunflowers. Reduced greenhouse gas emissions may result from the cultivation of degraded grasslands. Reduced greenhouse gas emissions may result from the cultivation of degraded grasslands.
12.	Multi-Feedstock Biodiesel Production from Esterification of Calophyllum inophyllum Oil, Castor Oil, Palm Oil, and Waste Cooking Oil H. Hadiyanto, Apsari Puspita Aini, W. Widayat, K. Kusmiyati, Arief Budiman, Achmad Rosyadi, 2020 (Hadiyanto et al., 2020)	This study was undertaken to examine the influence of the mixture of vegetable oils on the qualities of biodiesel.	Degumming and two-step esterification are performed to high free fatty acid raw materials before transesterification is mixed with other vegetable oils. Potassium hydroxide is employed as a homogeneous catalyst and methanol as another raw ingredient.	The acid value of C. inophyllum fell from 54 mg KOH/gr oil to 2.15 mg KOH/gr oil following two phases of esterification. The output of biodiesel from various feedstock was 87.926 % with a 6:1 methanol-oil molar ratio, 60 temperature, and 1 % wt catalyst.

1.5 Research Objective

1.5.1 General objective

Evaluating the energy and the environmental aspects of the multi-feedstock biodiesel production process.

1.5.2 Spesific objective

In particular, this research has several objectives, namely:

1) Analysing and synthesising the effect of long-term storage on the quality of palm oil biodiesel
2) Evaluating the environmental impact of palm oil biodiesel production life cycle
3) Analysing and synthesising the quality of multi-feedstock biodiesel produced from palm oil, used cooking oil, soybean oil, canola oil, and sunflower oil
4) Evaluating the energy balance of multi-feedstock biodiesel production life cycle is better or not than palm oil biodiesel production alone
5) Evaluating the environmental impact of multi-feedstock biodiesel production life cycle is better or not than palm oil biodiesel alone
6) Evaluating the environmental damage of multi-feedstock biodiesel production life cycle is better or not than palm oil biodiesel alone

1.6 Research Limitations

This research is limited by the fact that the simulation of the life cycle of multi-feedstock biodiesel production is still based on the conventional biodiesel industry method of transesterification using a homogenous catalyst. Currently, laboratory-scale biodiesel production technology has been developed that emphasizes the utilization of heterogeneous catalysts. Heterogeneous catalysts give the opportunity to enhance biodiesel quality, such as hydrocracking and hydroisomerisation utilising a modified zeolite catalyst to enhance cold flow characteristics. Future research will focus on the kinetics of the transesterification reaction utilising modified zeolite for hydrocracking and hydroisomerization in the biodiesel production process and its life cycle evaluation in order to address the limitations of this research.

Storage of biodiesel differs from real storage conditions in the company, particularly in bottles used to store biodiesel. In this investigation, a glass bottle was used to store biodiesel. There is no chemical interaction between glass bottles and methyl ester, which might contaminate biodiesel during storage, which is the reason why glass bottles are used. Meanwhile, biodiesel is stored in stainless steel and carbon steel tubes at the plant. Future biodiesel storage research is advised to use stainless steel or carbon steel.

Data at the stage of multiple crops plantations and oil palm plantation still relying on secondary data from scientific studies published in the international journals in the last ten years is also a limitation of study. The study's shortcomings are also shown in the inventory data for soybean, canola, and sunflower plantations. The inventory data on soybean and canola plantations was derived from secondary data on China's soybean plantations. Iran-based sunflower plantation secondary data were used for the sunflower plantation data inventory. Future LCA studies are strongly encouraged to use original data collected directly from observations in the field where LCA investigations are conducted.

The used software is SimaPro faculty licence 9.0.0.49. This software is used because it is open source and free for academic purposes and scientific publications. The license can be renewed annually. Consequently, this software is adequate for achieving study aims. SimaPro 9.0.0.49 is not the most recent release. The most recent release of SimaPro is version 9.3. It is suggested that future studies use SimaPro 9.3. The employed database is Ecoinvent 3.0. Ecoinvent 3.0 is not the most recent version of the database. The most current version of the Ecoinvent database is 3.8. Data inconsistencies are quite probable. It is suggested that future study use the Ecoinvent 3.8 database.

CML 2 Baseline 2000 version 2.05 was utilised in the study since it was the only version accessible on SimaPro faculty licence 9.0.0.49. SimaPro faculty licence 9.0.0.49 is not currently available for CML 2 Baseline 2016, the most recent version. The research used ReCipe 2008 Endpoint (H) version 1.13 because the hierarchist (H) approach is based on scientific agreement with reference to the time frame and plausibility of impact mechanisms. Then, the SimaPro faculty licence 9.0.0.49 does not include the ReCiPe 2016 version, which is newer than ReCiPe 2008.

1.7 Thesis Outline

This thesis comprises of nine chapters, beginning with this general introductory chapter and the chapter 2 description of the conceptual background. The ensuing six major research chapters (chapters 3–8) address the six research topics posed in section 1.3 and are followed by conclusions and future perspectives (chapter 9).

Chapter 2 provides a basis in theory. This chapter explains the theory of biodiesel production and life cycle evaluation.

The third chapter discusses the impact of room-temperature, dark storage on the quality of palm oil biodiesel (POB) and canola oil biodiesel (COB) (COB). POB and COB were stored in airtight containers at 22 °C and in the dark for 12 months (answer to research question 1).

Life cycle assessment (LCA) research on palm oil biodiesel production to evaluate Indonesia's environmental performance is presented in Chapter 4. Using an LCA technique, the researchers evaluated environmental indicators such as the carbon footprint, as well as the influence on human health, ecosystem diversity, and resource availability in the palm oil biodiesel production process (answer to research question 2).

The objective of Chapter 5 is to respond to Research Question 3 by producing and analysing biodiesel from a combination of five different oils, namely palm oil, used cooking oil, soybean oil, canola oil, and sunflower oil, through transesterification with varying oil:methanol mole ratios.

The eighth chapter details the energy balance of biodiesel production from multiple feedstocks. This research compares the energy balance of multi-feedstock biodiesel production to palm oil biodiesel production in Indonesia (answer to research question 4).

Chapter 7 examines the environmental impact of biodiesel production from diverse feedstocks. This research compares the environmental performance of simulated multi-feedstock biodiesel production in Indonesia to that of palm oil biodiesel production, in response to question 5 of the study.

Chapter 8 investigates environmental damage as a result of multi-feedstock biodiesel production in order to solve research question 6. This research compares the environmental damage at the end-point of simulated multi-feedstock biodiesel production to palm oil biodiesel production in Indonesia.

As the final chapter of this thesis, chapter 9 provides conclusions and future perspectives.

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