ASSESSMENT OF KAMANI BIODIESEL IN INDONESIA BASED ON LIFE CYCLE PERSPECTIVE

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A THESIS SUBMITTED AS A PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL TECHNOLOGY

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ABSTRACT

Kamani or *Calophyllum inophyllum* is a non-edible seed that has the potential to be a feedstock for biodiesel. Kamani trees are mostly found around coastal areas and are also known as forest trees. Kamani seed can be a promising alternative feedstock due to its high oil yield, simple cultivation procedure and non-edible seeds whereas palm oil which is currently used as biodiesel feedstock has environmental concerns and it is also produced for food thus raising issues about food versus fuel. The analysis of the energy inputs and outputs from kamani biodiesel show that its production is efficient because energy from output is higher than the input. Kamani biodiesel can also be considered renewable because its renewability factor at 5.52 (kamani biodiesel only) and 12.57 (all products) are substantially higher than 1. The study also assessed environmental impacts such as climate change, human toxicity, photochemical oxidant formation, particulate matter formation, particulate matter formation, terrestrial acidification, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity and fossil depletion. Those impacts were calculated by considering all emissions that came from life cycle of 1 ton kamani biodiesel production. The external costs of kamani biodiesel is higher than palm biodiesel but the price per liter of kamani biodiesel is slightly cheaper than palm biodiesel because of palm biodiesel production costs is higher.

Keywords: kamani, biodiesel, net energy balance (NEB), renewability factor, impact assessment

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INTRODUCTION

1.1 Rationale

The limitation of fossil fuels and its increased consumption require numerous research projects on alternative fuels in order to find the substitute. In Indonesia, the policy of using biofuel was initially launched in 2006 based on the issuance of a presidential instruction, and it was followed by an energy and mineral resources ministerial decree in 2008 stipulating the mandatory use of biofuel for transportation, industry and power plants. In September 2013, the government introduced an obligation to blend fossil diesel with a minimum 10 percent of biodiesel to reduce spending on oil and diesel imports. The B10 (BIOSOLAR) is produced by an oil company (PERTAMINA), consists of 10% palm diesel and 90% fossil diesel [1].

The study is focused on kamani (*Calophyllum inophyllum L.*) biodiesel where the more common plants for biodiesel are palm and jatropha. The utilization of jatropha oil as biodiesel feedstock is still problematic due to its low productivity. Palm oil is one of the most efficient oil bearing crops in terms of oil yield, land utilization, efficiency and productivity. However, competition between edible oil sources as food with fuel makes edible oil not an ideal feedstock for biodiesel production. This study assessed the environmental and economic impacts of kamani biodiesel by using Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) methodology. This study assessed whether kamani biodiesel has environmental advantages and economic benefits as compared to palm biodiesel and fossil diesel. The information is useful for Indonesian government, so that kamani biodiesel can be considered as a promising alternative fuel because it is a non-edible plant.

1.2 Literature Review

1.2.1 Life Cycle Assessment of Biodiesel

Biodiesel is one of the most common renewable fuels used at the moment, especially when fossil fuels are starting to be depleted. To produce biodiesel, there are many oil plants can be used as feedstock like oil palm, jatropha curcas, kamani and so on but there are some issues related to competition of edible oil plants, production cost, environmental impacts, land use changes, etc. Many studies have been conducted to discuss about those issues and one of the tool to explain it is life cycle assessment.

Since kamani is a new alternative as biodiesel feedstock, there is still limited information about it and almost no studies about its life cycle assessment have been conducted. But there are many references and studies on palm biodiesel because it is the most common feedstock for biodiesel in the world especially in Indonesia and used in biodiesel blend, B7 or B10. It is chosen as feedstock because of its high yield and good business prospect on both food and energy. A previous study conducted a study of life cycle assessment on palm biodiesel in Indonesia to investigate the environmental impacts of the production process and energy analysis from all life cycle process. It is found that the biggest contributors of global warming potential are from the use of fertilizers during cultivation activity. The results from energy analysis has also been done by calculating net energy ration (NER), net energy balance (NEB), and renewability factor as considerations. From the calculation of NER and NEB, it indicates that biodiesel from palm oil has high energy efficiency and can help to reduce dependence on fossil fuels [2].

In Thailand, there are also some studies about the life cycle assessment of biodiesel from palm oil.[3] has conducted environmental evaluation of biodiesel diesel from palm oil. It is found that the major water requirement for the production of biodiesel comes from oil palm agriculture. Nitrogen is the largest input from fertilizer although potassium and phosphorus are also significant contributors. Diesel requirements come primarily from agriculture and palm oil production. The transesterification process has the largest demand for electricity (kWh).

Yee et al. [4] stated that palm oil would be a more sustainable feedstock for biodiesel production as compared to rapeseed oil. In terms of GHG assessment, it can be concluded that the production of palm and rapeseed biodiesel brings no negative impact to the environment as the amount of CO_2 emitted to the atmosphere is much lower than the CO_2 absorbed from the atmosphere because provided forests are not converted to plantations.

Sahoo et al. [5] have tested the performance of kamani biodiesel, used as a substitute fuel in a diesel engine. The result of the test shown that higher percentage of kamani biodiesel in diesel tended to decrease the exhaust smoke substantially. Besides, there was reduction in HC and PM in kamani biodiesel whereas CO and NOx were slightly increased. The neat kamani biodiesel was shown reduced in exhaust emission as compared to evaluated diesel.

According to Ong et al. [6], in Malaysia using palm oil as feedstock for producing biodiesel is still economically feasible, the competition of edible oil plants as food with fuel makes edible oil not an ideal feedstock. This shifts the attention to non-edible oil plants like Jatropha curcas and kamani which are grown in tropical and sub-tropical climate country. Besides, kamani oil can be considered as potential biodiesel fuel and could be transesterfied. But further research and study need to be conducted in order to know more about its property characteristic, long-term wear and tri-biological analysis along with injection timing and duration for better combustion in diesel engines.

1.2.2 Life Cycle Cost of Biodiesel

Substituting fossil fuels or palm biodiesel with this kamani biodiesel can be feasible if it is also economically viable. Hence, evaluating the life cycle cost for the whole kamani biodiesel production process is needed so it can be compared.

For all phases, the cost must be known in order to run the process well, thus cost assessment in this life cycle of kamani biodiesel which are calculated including installation, operation, maintenance, as well as recycled or reuse process. In addition, external cost of polluted emissions from the process is important aspect to be considered, as it can be a way to encourage people, particularly industries to reducing pollution since it has saving in term of money. By evaluating the entire life cycle of kamani biodiesel production, some key factors that have a significant impact on kamani biodiesel price can be obtained and the solution to reduce the price can be found so that it could be competitive with fossil fuels an palm biodiesel.

The environmental costs show that biodiesel blends give more environmental benefits than petroleum diesel. From the full costs analysis (production cost combined with environmental externalities), it is observed that higher percentages of biodiesel blends result in lesser environmental costs but higher production costs. However, the results reveal that B5 and B10 are able to compete with diesel once the environmental costs have been internalized into the production costs. The results show that the highest environmental cost stems from the depletion of fossil energy resources followed by CO_2 emissions. An increase in the percentage of biodiesel blend can significantly help reducing both fossil resources depletion and CO_2 emissions. The environmental costs arising from the increase of NOx and N_2O emissions as well as land use expansion for energy crop cultivation are lower than the total environmental benefits arising from the production and use of the biodiesel blends covered [7].

1.3 Research Objectives

The objectives of this study are given below:

- ❖ To investigate the environmental impact of Kamani Biodiesel by using Life Cycle Assessment (LCA) methodology.
- ❖ To investigate kamani biodiesel production and utilization costs by using Life Cycle Cost (LCC) methodology, including the external cost.
- ❖ To find which process of kamani biodiesel will contribute the most to the environment and to the cost.

1.4 Scope of Research Work

This study focuses on life cycle assessment and life cycle costs, of which the environmental impacts are assessed. External costs of kamani biodiesel are included. The unit process of the life cycle includes the following:

1. Kamani plantation
2. Feedstock processing
3. Biodiesel conversion

Environmental impacts assessed are climate change, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial acidification, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity and fossil depletion.

Equipment and technologies that is used in this study is a pilot project scale and it is assumed can be used for 25 years. This study will be conducted and is valid in Cilacap, Central Java, Indonesia.

CHAPTER 2
THEORIES

2.1 Kamani as Feedstock for Biodiesel

Kamani or *Calophyllum inophyllum*, commonly known as Nyamplung in Indonesia, is a non-edible oilseed ornamental evergreen tree belonging to the Clusiaceae family. The scientific name of "Calophyllum" comes from the Greek word for "beautiful leaf". It grows along coastal areas and adjacent lowland forests, although it occasionally occurs inland at higher elevations. It is native to eastern Africa, southern coastal India, Southeast Asia, Australia and the South Pacific. *Calophyllum inophyllum* is also often called the 'Alexandrian Laurel' in English and other vernacular names in various countries, as shown in Table 2.1.

Table 2.1 Vernacular names for Calophyllum inophyllum

Country	Vernacular names
Bangladesh	Punnang
Cambodia	Khtung, Kchyong
English	Alexandrian laurel, Borneo mahogany, Tamanu
Hawaii	Kamani
India	Polanga, Sultan Champa
Indonesia	Nyamplung, Bintangur
Malaysia	Penaga Laut, Bintangor
Myanmar	Ponnyet
Palau	Btaches
Papua New Guinea	Beach calophyllum
Philippines	Butalau, palo maria, bitaog
Thailand	Krathing, saraphee (northern), naowakan (Nan)

Calophyllum inophyllum is a medium and large-sized evergreen sub-maritime tree that averages 8–20m (25–65 ft) in height with a broad spreading crown of irregular branches. It has elliptical, shiny and tough leaves. The flower is around 25 mm wide and occurs in racemose or paniculate inflorescences consisting of 4–15 flowers.

The fruit (ballnut) is a round, green drupe reaching 2–4 cm (0.8–1.6 in.) in diameter and having a single large seed. When it is ripe, the fruit is wrinkled and its colour varies from yellow to brownish-red. The grey, ligneous and rather soft nut contains a pale yellow kernel, which is odourless when fresh. *Calophyllum inophyllum* kernels have very high oil content (75%) and the oil contains approximately 71% of unsaturated fatty acids (essentially oleic and linoloeic acids) [9]. It is obtained by cold expression and yields refined, greenish yellow oil, similar to olive oil, with an aromatic odor and an insipid taste. Fruits are usually borne twice a year and it produces up to 100 kg of fruits and about 18 kg of oil. *Calophyllum inophyllum* is grown in warm temperatures in wet or moderate conditions and requires mean annual rainfall around 1000–5000mm [10]. It is highly tolerant to strong winds, salt spray and brackish water tables. The trees are sensitive to frost and fire. The wind and salt tolerance makes it suitable for sand dune stabilization [11]. Plantation can be done at a density of 400 tree/ha [12]. The average oil yield is 11.7 kg-oil/tree or 4680 kg-oil/ha.

Traditional Pacific Islanders used Calophyllum wood to construct the keel of their canoes while the boat sides were made from breadfruit wood. In Java, the tree is believed to have diuretic properties. The emetic and purgative gum extracted from the plant is used for the treatment of wounds and ulcers. An infusion of gum, bark and leaves is used for sore eyes. *Calophyllum inophyllum* oil from the fruit traditionally has been used for medicines and cosmetics. It has been used empirically for centuries in Madagascar to treat wound, facial neuralgia, skin ailments and hair loss. The oil is also used in varnishes and as lamp oil.

The fruits are used for human consumption although they are reported to be slightly toxic. Crude *Calophyllum inophyllum* oil generally has a high acid value 44 mg KOH/g (22% FFAs) and thus a dependable technique for converting this *Calophyllum inophyllum* oil to biodiesel is very much required. The fatty acid methyl ester of *Calophyllum inophyllum* seed oil meets all of the major biodiesel requirements in the United States standard (ASTM D 6751-06) and European Union standard (EN 14214) (Azam et al., 2005). According to Sahoo et al. (2009), it is shown that the chemical characteristics of the *Calophyllum inophyllum* oil methyl ester were found to be in the close range of diesel engine requirements. However, further research and study need to be carried out before suggesting long term application of *Calophyllum inophyllum* oil based biodiesel.

Current development on kamani, Forest Research Institute Malaysia (FRIM) and Forestry Research and Development Agency, Indonesia (FORDA) had joint forestry research and development together especially in biofuel area from year 2007 to 2010 for 5 years [13]. In 2009, a group of researchers from FRIM had joined training on *Calophyllum inophyllum* as biofuel to research and exchange information about *Calophyllum inophyllum* as an alternative biodiesel fuel conducted by FORDA in Indonesia [14]. This is the very first step Malaysia involved in *Calophyllum inophyllum* research as a biodiesel fuel.

The cultivation of *Calophyllum inophyllum* oil can be considered as a potential alternative for renewable energy sources and the oil could be transesterified. However, there is very limited information is available about the research and production of biodiesel from *Calophyllum inophyllum* oil. Therefore, further study and research *Calophyllum inophyllum* fuel property measurement, long-term wear and tribological analysis of biodiesel, injection timing and duration for better combustion of biodiesel in diesel engines need to be carried out.

2.2 Kamani Oil Biodiesel Production Process

According to the previous study by Jahirul et al. [15], there some steps in producing kamani biodiesel which are:

1. Kernel Extraction

   Preparing the seeds for oil extraction involved first removing the outer layers to expose the kernel. It was necessary to crack the seeds open in order to obtain kernels for further preparation and processing. The seed cracking process used two methods: stompers and mallets. For the stomper, a large number of seeds were placed on the ground and worked until a number had been cracked, then the kernels and the waste husk were removed. For the mallet, operators placed a handful of seeds on the table surface and cracked them individually, before removing the kernels and the waste husk

2. Kernel Drying

   Experiments were conducted to investigate the optimum moisture content of the seed kernel for high oil yield. Additionally, mulched and unmulched kernels were also investigated to determine the effect of mulching on the rate of drying. The drying process was conducted using a laboratory scale Clayson electric oven with temperature controller.

3. Oil extraction

Two methods can be used for extracting oil from the prepared seed kernel. The first is mechanical oil extraction using an electric powered screw press, and the second is chemical oil extraction using n-hexane as a solvent. The mechanical oil extraction and experiment were conducted using a Mini 40 screw press at CPWS, Central Queensland University (CQU). Actually, the screw press used in the study was not designed for Beauty Leaf seeds. It was realized that using this press for the oil extraction not only would this be challenging, but would require a degree of experimentation to adjust pressure and speed. For chemical oil extraction, dried seed kernels samples were ground using the blender and coffee grinder to obtain a fine consistency to maximize particle surface area. The ground kernels were put into conical flasks in which hexane as added at a ratio of 2:1 (mL hexane: grams kernel). The mixture was given an initial stir to ensure that all kernels were wetted with hexane.

2.3 Life Cycle Assessment

Life Cycle Assessment (LCA) is a tool used to evaluate potential environmental impact of a product or a process. The approach stems from conventional environmental assessment which focuses on part of product's life such as manufacturing phase or end-of-life disposal. Rather than just looking at individual pollutant and its single impact on the environment, or the amount of waste ending up in a landfill or an incinerator after its service life, LCA is a cradle-to-grave approach [16].

As environmental awareness increases, industries and businesses are assessing how their activities affect the environment. Society has become concerned about the issues of natural resource depletion and environmental degradation. Many businesses have responded to this awareness by providing "greener" products and using "greener" processes. The environmental performance of products and processes has become a key issue, which is why some companies are investigating ways to minimize their effects on the environment. Many companies have found it advantageous to explore ways of moving beyond compliance using pollution prevention strategies and environmental management systems to improve their environmental performance. One such tool is LCA. This concept considers the entire life cycle of a product.

Life cycle assessment is a "cradle-to-grave" approach for assessing industrial systems. "Cradle-to-grave" begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product and process selection. Figure 2.1 below shows a diagram of possible life cycle stages and inputs or outputs measured, which are considered in LCA.

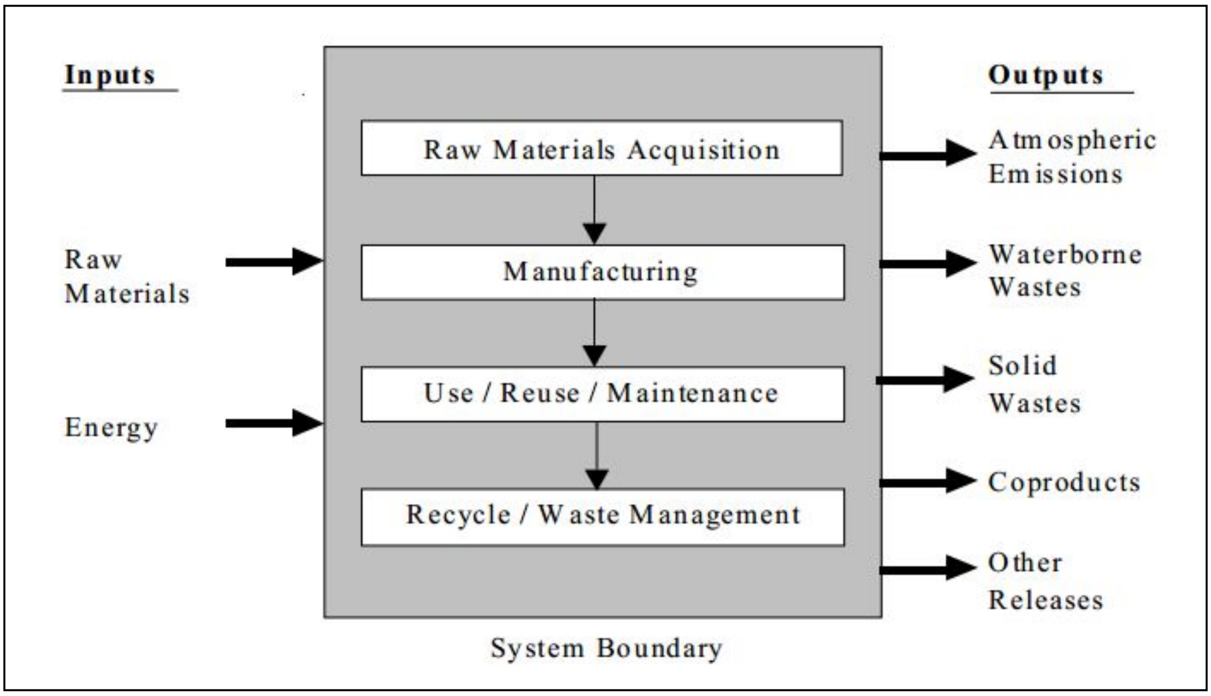

Figure 2.1 Life cycle stages

2.3.1 Goal and Scope

Goal definition and scoping is the phase of the LCA process that defines the purpose and method of including life cycle environmental impacts into the decision-making process. In this phase, the following items must be determined: the type of information that is needed to add value to the decision-making process, how accurate the results must be to add value, and how the results should be interpreted and displayed in order to be meaningful and usable.

2.3.1.1 Functional Unit

The functional unit is a key element of LCA which has to be clearly defined. The functional unit is a measure of the function of the studied system and provides a reference to which the inputs and the outputs can be related. This enables comparison of two essential different systems. For example, the functional unit for a paint system may be defined as the unit surface protected for 10 years. A comparison of the environmental impact of two different paint systems with the same functional unit is therefore possible.

2.3.1.2 System Boundary

The system boundaries determine which unit processes to be included in the LCA study. Defining system boundaries is partly based on a subjective choice, made during the scope phase when the boundaries are initially set. The following boundaries can be considered:

- Boundaries between the technological system and nature. A life cycle usually begins at the extraction point of raw materials and energy carriers from nature. Final stages normally include waste generation and/or heat production.
- Geographical area. Geography plays a crucial role in most LCA studies, e.g. infrastructures, such as electricity production, waste management and transport systems, from one region to another. Moreover, ecosystems sensitivity to environmental impacts differs regionally too.
- Time horizon. Boundaries must be set not only in space, but also in time. Basically LCAs are carried out to evaluate present impacts and predict future scenarios. Limitations to time boundaries are given by technologies involved, pollutants lifespan, etc.
- Boundaries between the current life cycle and related life cycles of other technical systems. Most activities are interrelated, and therefore must be isolated from each other for further study. For example the production of capital goods, economic feasibility of new and more environmentally friendly processes can be evaluated in comparison with currently used technology.

2.3.2 Inventory Analysis

Inventory analysis is based primarily on system analysis, treating the product process chain as a sequence of subsystems that exchange inputs and outputs [17]. The objective of the inventory is to collect environmentally relevant information from the processes identified during the scope definition and are included in the model of the product system [18].

It comprises all stages dealing with data retrieval and management. The data collection forms must be properly designed for optimal collection. Subsequently, the data are validated and related to the functional unit in order to allow the aggregation of results. A very sensitive step in this calculation process is the allocation of flows e.g. releases to air, water and land. Most of the existing technical systems yield more than one product. Therefore, materials and energy flows regarding the process as a whole, as well as environmental releases must often be allocated to the different products. This is recommended to be made according to a given procedure:

- Wherever possible, allocation should be avoided.
- Where allocation is not avoidable, inputs and outputs should be partitioned between its different functions or products in a way that reflects the underlying physical relationships between them.
- If the latter is not possible, allocation should be carried out based on other existing relationships (e.g. in proportion to the economic value of products).

2.3.3 Impact Assessment

Life cycle impact assessment (LCIA) aims to evaluate the significance of potential environmental impacts using the results coming out from the LCI phase. The ISO14040 suggests that this phase of an LCA is divided into the following steps:

Mandatory elements:

- Selection of impact categories, category indicators and characterization models.
- Classification, i.e. assignment of individual inventory parameters to impact categories, e.g. CO_2 is assigned to Global Warming. Common impact categories are Global Warming, Ozone Depletion, Photo oxidant Formation, Acidification and Eutrophication.
- Characterization, i.e. conversion of LCI results to common units within each impact category, so that results can be aggregated into category indicator results.

Optional elements:

- Normalization. The magnitude of the category indicator results is calculated relatively to reference information, e.g. and old products constitutes baseline when assigning a new product.
- Weighting. Indicator results coming from the different impact categories are converted to a common unit by using factors based on value-choices.
- Grouping. The impact categories are assigned into one or more groups sorted after geographic relevance, company priorities, etc.

The methods that are usually used for LCIA are e.g. EDIP 2003, CML 2 Baseline 2000, Eco-Indicator 99, ReCiPe, and IMPACT 2000+.

2.3.4 Interpretation

The aim of the interpretation phase is to reach conclusions and recommendations in accordance with the defined goal and scope of the study. Results from the LCI and LCIA are combined together and reported in order to give a complete and unbiased account of the study. The interpretation is to be made iteratively with the other phases.

The life cycle interpretation of an LCA or an LCI comprises three main elements:

- Identification of the significant issues based on the results of the LCI and LCIA phases of a LCA.
- Evaluation of results, which considers completeness, sensitivity and consistency checks.
- Conclusions and recommendations.

In ISO 14040 standard, it is recommended that a critical review should be performed. In addition, it is stated that a critical review must have been conducted in order to disclose the results in public.

2.4 Life Cycle Cost Analysis

ISO 14040 indicated that LCA typically does not address the economic or social aspects of a product, but the life cycle approach and methodologies described in this International Standard can be applied to these aspects. Therefore, Life Cycle Costs can be done as an extension of LCA to the economic dimension (UNEP).

Life Cycle Costing (LCC) is a methodology that will incorporate costs and benefits that occur over the entire life cycle of a product into procurement decisions, rather than considering the initial capital cost of a product only.

2.4.1 Economic Input Analysis

The major economic factors to consider for input costs of biofuel production are feedstock and energy-related. The type, availability, and price of raw material all factor into profitability of producing biofuel. Intermediate economic factors include the cost of labor both in operating expenses and administrative costs. These costs are directly related to economies of size for oil plants. The total cost of capitalization of the ethanol facility is also directly based on the facility size. Other minor economic input factors to consider include the cost of chemicals, fresh water, waste effluent and denaturant. Minor economic concerns have little to do with either the location of a plant or the economies of size associated with large plants [19].

2.4.2 Time Value of Money

The fundamental concept underlying the idea time value of money is that the value of a given sum of money depends on both the amount of money and the time when the money is received or paid. Since money has time value, one should not add or subtracted unless it occurs at the same point of time [19]. In considering the time value of money, it is convenient to represent mathematically the relationship between the current or present value as a single sum of money and its future value. Letting time be measured in years, if a single sum of money has a current or present value of P, its value in n year would be equal to

$$F = P\,(1 + i)^n$$

where F is future value and I is interest rate per interest period.

When there are many cash flows involved, solving for the present worth or future equivalent by treating each cash flow individually, it can be time consuming. A uniform series of cash flows exist when all cash flows in a series are equally sized and spaced. In the case of uniform series, the present worth equivalent is given by

Where

P = Present value

A = Annual payment

I = Interest rate

2.4.3 Customer Price Index

Money has its time value, which means that the buying power of 1 unit of money will be different each time. A sustained increase in the general level for prices of goods and services cause a decrease in purchasing power, known as inflation without an accompanying increase in the values of goods and services [19]. An inflation rate determined by one of approaches, so called Consumer Price Index (CPI), was developed by the U.S. Department of Labor's Bureau of Labor Statistic. Published monthly, CPI measures the price changes that occur from one month to the next for specified set of products. The CPI is a marker basket rate, in that it is based on 80,000 prices that are recorded in the urban areas. In Indonesia, CPI or Indeks Harga Konsumen (IHK) was surveyed by Badan Pusat Statistik (BPS – Statistics Indonesia) and cover 66 cities. The data cover 284 – 441 goods and services which are classified into seven expenditure groups namely: foodstuff; prepared food, beverage, cigarette and tobacco; housing, water, electricity, gas and fuel; clothing; health; education, recreation and sports; and transport, communication and financial services. Each group consists of several sub groups, and then in every sub group there are several items. The Indonesian CPI is calculated by modified Laspeyres formula. Arithmetic mean is used in calculating the average (mean) of goods and services price but for some seasonal goods and services, geometric one is used [19].

2.5 External Costs

Traditional and conventional costs are investments costs, production costs, operating costs, waste management costs, liability costs (legal services, monitoring, taxes charges, and fees). Indirect and hidden costs can be a value of lost inputs of raw materials, incremental costs of substitutes of raw materials, environmental costs of intermediates or power generation, costs of environmental labeling, costs of take-back of used packaging and environmentally-driven research and development. External cost is a social cost of environmental damages (health, corrosion, biodiversity, etc.) and it is external to market price system (economic valuation). Total environmental Cost Assessment (TCA) is internal and external costs.

CHAPTER 3
METHODOLOGY

3.1 Life Cycle Modeling

The life cycle thinking has become a key to the development of sustainability in recent years, to avoid shifting problems from one place to another, from one geographic region to another and from on environmental medium to another (UNEP, 2004; in [20]). Life cycle assessment (LCA) is a part of life cycle thinking, which is a quantitative tool to measure environmental impact, based on accounting the material and energy input and output in entire life cycle. Thus, LCA is applied to this study for assessing the environmental impact of kamani-based diesel, and comparing the environmental benefit with palm diesel and fossil diesel. This life cycle is from well to wheels.

3.1.1 Life Cycle Assessment

3.1.1.1 Goal and Scope Definition

Based on a mandate from the Indonesian government to raise biodiesel blending percentage to 10%, the demand for palm biodiesel also increased. The goal of this study is about biodiesel from kamani seed as potential feedstock for Indonesia in order to fulfill demand of biodiesel. This study will evaluate environmental impacts and the life cycle cost so that it could be compared to existing fuels like fossil diesel and palm diesel. The scope of this study includes the entire life cycle of kamani biodiesel whose environmental impacts (climate change, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial acidification, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity and fossil depletion) were assessed.

3.1.1.2 System Boundary

The system boundary of the study is all process as from kamani cultivation to kamani biodiesel production. The diagram flow can be seen in Figure 3.1.

3.1.1.3 Inventory

The data quality requirements depended on the geographic area, unit processes, technology coverage, etc. In this study, data was collected from the field study and interviews, while the literature and reports were used as secondary sources. The data collection of kamani cultivation was obtained from the owner of pricate kamani plantation and Forestry Service of Cilacap (Dinas Kehutanan Cilacap). All kamani cultivation was assessed, including planting, post planting, and harvesting. The fertilizers, fungicide and other chemicals used during cultivation and biodiesel production. The data of biodiesel conversion were obtained from Koperasi Jarak Lestari, which is located in Cilacap, Central Java. The data needed included material, energy inputs and outputs, as well as the usage of equipment.

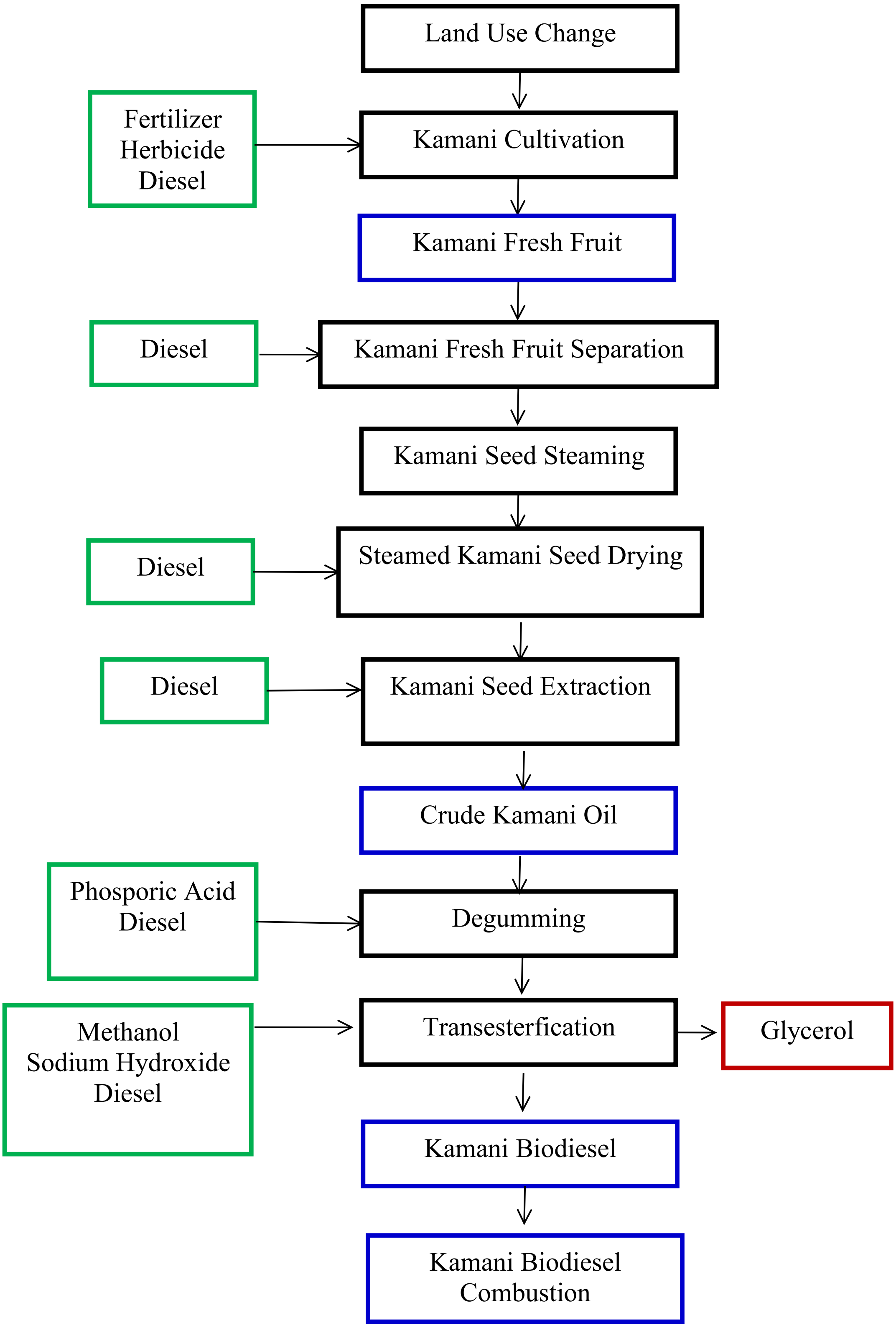

Figure 3.1 System boundary of the study

3.1.1.4 Impact Assessment

In this study, there are four environmental impacts to assess which climate change, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial acidification, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity and fossil depletion. The indicators of those environmental impacts are the emissions of CO_2, CH_4, SO_2, NOx, NO, NO_2, and N_2O. The calculation was done by Microsoft Excel with the methodology ReCiPe midpoint version 1.09. The potential environmental impacts are calculated as follows:

$$EP(j)_i = Q_i \times EP(j)$$

Where

$EP(j)_I$ = the emission's potential contribution to the environmental impact (j)

Q_i = the magnitude of emissions of substance (i)

$EP(j)$ = the substance's equivalency factor for the environmental impact category (j)

j =climate change, human toxicity, photochemical oxidant formation, particulate matter formation, particulate matter formation, terrestrial acidification, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity and fossil depletion.

Equivalency factor (EF) for the impact categories on focused gases are shown in Table 3.1

Table 3.2 Equivalency Factors for Substances

Climate Change (kg CO_2-eq/kg substance)	
Substance	**Factor**
Carbon dioxide (CO_2)	1
Dinitrogen monoxide (N_2O)	298
Methane (CH_4)	25
Terrestrial Acidification (kg SO_2-eq/kg substance)	
Substance	**Factor**
Sulfur oxides (SO_x)	2.45
Ammonia (NH_3)	1
Nitrogen oxides (NOx)	0.56
Photochemical Oxidant Formation (kg NMVOC-eq/kg substance)	
Substance	**Factor**

Carbon monoxide (CO)	0.0456
Sulfur dioxide (SO_2)	0.0811
NMVOC (non-methane volatile organic compounds)	1
Nitrogen oxides (NOx)	1
Marine Eutrophication (kg N-eq/kg substance)	
Substance	**Factor**
Water emission: Ammonia (NH_3)	0.824
Air emission : Ammonia (NH_3)	0.092
Nitrogen oxides (NO_x)	0.389
Human Toxicity (kg 1.4 DB-eq/kg substance)	
Substance	**Factor**
Mancozeb	0.000836
Terrestrial Ecotoxicity (kg 1.4 DB-eq/kg substance)	
Substance	**Factor**
Mancozeb	0.0471
Freshwater Ecotoxicity (kg 1.4 DB-eq/kg substance)	
Substance	**Factor**
Mancozeb	0.0137
Marine Ecotoxicity (kg 1.4 DB-eq/kg substance)	
Substance	**Factor**
Mancozeb	0.000039
Fossil Depletion (kg oil-eq/kg substance)	
Substance	**Factor**
Oil	1.09

3.1.1.6 Interpretation

Evaluating the results of the inventory analysis and impact assessment, so that the conclusion can be obtained, the findings then can be used to give recommendations for improving the environmental performance of kamani biodiesel.

3.1.2 Life Cycle Costs

Life cycle cost (LCC) is used in this study with the same system specifications as LCA, to evaluate the cost of producing biodiesel from kamani seed. All the costs of the process included in LCC are capital investment, material, energy (fuel, electricity), labor, transportation, maintenance, and miscellaneous costs. The results of calculation will be compared with fossil fuels and palm biodiesel which are obtained from previous research.

3.1.2.1 Data Collection of LCC

The data of kamani cultivation costs was obtained from the Forestry Service of Cilacap (Dinas Kehutanan Cilacap) in Central Java. The costs that are counted are as follows:

1. Land preparation
2. Seed
3. Fertilizers purchase and application
4. Labors in land preparation planting, fertilizing, harvesting
5. Tools
6. Transportation of seed, chemicals, and harvest

The data of biodiesel conversion cost was collected from Koperasi Jarak Lestari. The costs include kamani as feedstock, investment/capital cost, operating cost, transportation and distribution. Data of fossil diesel and palm diesel prices was obtained from previous research in thesis, journal, etc.

3.1.3 External Cost

External costs are recommended to be included in fuels prices especially if there is comparison among several fuels from different feedstocks, as it would make it fair to also consider their environmental aspects. In this study, default indices were calculated for impact category indicators. Background information was extracted from LCA-based inventory of the process studied and the results were represented as willingness to pay (WTP) of the society. The EPS model as a tool for external cost estimates was developed in Sweden adopted WTP approximation model on Thailand have been done by NEPO (NEPO/DANCED, 1998, [21]. In this study, externalities were addressed using Indonesian

WTP. Comparison of GDP per capita then used as base of comparison. To make a fair comparison, GDP can be expressed in terms of PPP (Purchasing Power Parity) using the formula:

Where:

$WTP_{Indonesia}$ = Willingness To Pay in Indonesia

WTP_{Sweden} = Willingness To Pay in Sweden (basic method)

PercapGDP $(PPP)_{Indonesia}$ = GDP percapita of Indonesia in term of PPP

PercapGDP $(PPP)_{Sweden}$ = GDP percapita of Sweden in term of PPP

In this study, external cost are calculated based on the formula:

Where:

Ext = Total External Cost

i = Emission

WTP_i = Willingness to pay

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Data, Emission Factors, and Energy Factor Sources

The data of this study was collected in September 2014 in several places in Indonesia: Research Institute of Forest Biotechnology and Plant Breeding, Yogyakarta and Forestry Office, Purworejo for kamani cultivation, CV Koperasi Jarak Lestari, Kroya for biodiesel production and also from publication of a previous study related with this topic. This data of kamani cultivation and biodiesel were collected over a period of one year. Data sources of input energy, emission factor and energy factor are shown in Tables 4.1, 4.2 and 4.3.

Table 4.1 Data Sources for each Life Cycle Stage

Life Cycle Stage	Item	Data Source
Kamani Cultivation	NPK Fertilizer	Research Institute of Forest Biotechnology and Plant Breeding, Yogyakarta
	Fungicide	
	Insecticide	
	Diesel in transportation	CV Koperasi Jarak Lestari, Kroya
Kamani Oil Production	Phosphoric Acid	CV Koperasi Jarak Lestari, Kroya
	Diesel for machine	
Biodiesel Production	Methanol	CV Koperasi Jarak Lestari, Kroya
	Sodium hydroxide	
	Sulfuric acid	
	Diesel for machine	

Table 4.2 Data Sources of Energy Factors

Life Cycle Stage	Item	Data Source
Kamani Cultivation	NPK Fertilizer [3]	Pleanjai and Gheewala, 2009
	Fungicide [22]	Audsley et al., 2009
	Insecticide [22]	
	Diesel in transportation [23]	Prueksakorn and Gheewala, 2008
Kamani Oil Production	Phosphoric Acid [3]	Pleanjai and Gheewala, 2009
	Diesel for machine [23]	Prueksakorn and Gheewala, 2008
Biodiesel Production	Methanol [3]	Pleanjai and Gheewala, 2009
	Sodium hydroxide [3]	
	Sulfuric acid [3]	
	Diesel for machine [23]	Prueksakorn and Gheewala, 2008
Kamani Biodiesel (main product and co-products)	Kamani Biodiesel [24]	Rahman, 2013
	Glycerol [23]	Prueksakorn and Gheewala, 2008
	Press cake [25]	Wahyuni et al., 2010

Table 4.3 Data Sources for Emission Factors

Life Cycle Stage	Item	Data Source
Kamani Cultivation	NPK Fertilizer [26]	Bilan Carbone, 2007
	Fungicide [26]	
	Diesel in transportation [27]	EEA, 2013
Kamani Oil Production	Phosphoric Acid [28]	Althaus, 2007
	Diesel for machine [27]	EEA, 2013
Biodiesel Production	Methanol [28]	Althaus, 2007
	Sodium hydroxide [28]	
	Sulfuric acid [28]	
	Diesel for machine [27]	EEA, 2013

4.2 Kamani (Calophyllum inophyllum) Biodiesel in Indonesia

Biodiesel from kamani was very popular in Indonesia during the years 2008 to 2011 where government programs for biofuel were focused on kamani. Government established three energy-independent villages in Central Java province and the locals were supplied with pressing machine to produce oil from kamani, converted it to biodiesel and used the biodiesel for locals' daily activities. This program was implemented over several years and then its popularity started to decrease then it stopped, it happened not because of lack of feedstock but the price of 1 kg kamani fruit was increased from Rp 500/kg to Rp 750/kg. But at the moment, there are locals who still produce kamani crude oil daily by order. It is usually ordered by researchers, cosmetics industry and pharmacy industry.

Kamani tree plantations were expanded by Perum Perhutani Unit I Central Java (forestry office) in 1980 on land outside forests in coastal area. The reason of planting kamani in coastal area that time was because of land occupancy and coastal erosion. Forestry office provided the kamani seed for the area and let the trees grow while at the same time also solved those mentioned issues.

There are about 350 hectares of kamani plantation in Central Java, which are partly private and partly owned by the government. Because kamani cultivation is still in early stage, so the production of kamani fruit from year 2010 – 2015 can be harvested in a large amount from natural forest.

At the moment, there is no exact data about kamani plantation in Indonesia because some of them grew wildly but Citra Landsat7 ETM satellite indicated that kamani trees area along the beach in all provinces in Indonesia is around 480 hectares.

4.3 Inventory Analysis

4.3.1 Kamani Cultivation Inventory

Growing kamani trees is quite simple because they can grow by themselves even without treatment but to have a large harvest, some treatment is needed. This tree can be easily found around coastal areas. Kamani can be cultivated by two methods which are generative (seed) and vegetative (macro and micro). Generative growth can be conducted with mature seed and kamani tree will produce fruit around 7 years after planting. Before planting kamani tree on land, a seed is planted in a bag with usual treatment such as watering or applying fertilizers, and fungicides. After six months, the kamani tree is ready to be planted on land. Kamani trees are planted on land that is already prepared by making a hole of 30 cm × 30 cm × 30 cm and adding 2 kg of manure for each tree. The planting should be in an ideal weather with rainfall more than 100 mm where humidity reaches field capacity. The yield per tree per year is 375 kg fresh fruit for 25 years of economic life. The tree density per hectare is around 400 trees and higher fruit yield can be achieved by lessening the tree density.

The kamani tree produces fruit throughout the year because the tree grows high so the harvest time is usually happened when the fruits are ripe and fall down to the ground. The tree is productive until around 50 years. Kamani is collected from the falling fruit that is already mature or it can be collected from the branch by equipment. Before seeding, kamani seed is separated from the fruit and this should be done by submerging the fruit in the water for two days. After that by using hand the seed is separated from the fruit then dry it in room temperature for two days. The best quality kamani seed is selected manually by picking the best physical appearance of seed where there is no disease seen on the seed. NPK 15-15-15 fertilizer was used in this study during the seeding time for four months and also fungicide that used was mancozeb. Fossil diesel that was counted in this study was from transport of chemicals to seeding place and fruits to production unit

During this cultivation activity, there are emission gases from each material input such fertilizer, fungicide and also fossil diesel. The inventory of cultivating 1 ton kamani fruit is shown in Table 4.4.

Table 4.4 Inventory of Production of 1 ton kamani fruit

	Item	Amount					Unit
INPUT	Seed	67					seed
	Manure	133					kg
	N fertilizer	1.93					kg
	P fertilizer	1.93					kg
	K fertilizer	1.93					kg
	Fungicide	1.34					g
ENERGY	Diesel for transportation	4.15					kg
PRODUCT	Kamani	1					ton
	Substance	Fertilizer Production	Fertilizer Application	Fungicide	Transportation	Total	Unit
				Mancozeb			
EMISSION	CO_2	6.06E+03		3.30E+00	1.30E+01	6.07E+03	g
	CO				1.38E+01	1.38E+01	g
	N_2O	2.75E+02	6.35E-01	8.71E-05	3.61E-01	2.76E+02	g
	CH_4	8.70E+03		1.62E-02	2.40E-01	8.70E+03	g
	NMVOC				2.91E+00	2.91E+00	g
	NOx	9.95E+01		8.72E-03	5.38E+01	1.53E+02	g
	NH_3	3.44E+03	1.30E+02		2.70E-01	3.57E+03	g
	SO_2					0.00E+00	g
	TPM				4.57E+00	4.57E+00	g
	C_2F_6	8.10E-05		4.15E-08		8.11E-05	g
	CF_4	1.17E-03		3.31E-07		1.17E-03	g

4.3.2 Kamani Biodiesel Production Inventory

The biodiesel plant in CV Koperasi Jarak Lestari can produce 300 liters of crude oil everyday and the maximum capacity of equipment for processing crude oil is 800 liters. There are some preparation should be conducted before extracting the seed, seed is needed to be separated from its shell by crusher machine. After separation, steaming and drying process, the dry kamani seeds are ready for oil extraction. The mass of dry kamani seed is half of the fresh fruit.

To produce 1 ton of kamani biodiesel, about 7,448 kg of kamani fresh fruit is needed. The mass flow of 1 ton kamani biodiesel production is shown in Figure 5. After separation, steaming and drying process, the dry kamani seeds are ready for oil extraction. The mass of dry kamani seed is half that of the fresh fruit. The ready wet seed is pressed by machine to obtain the crude kamani oil, which is then filtered. The density of kamani oil is 0.92 kg/liter. Because in kamani crude oil there is gum, degumming process should be done to remove the gum by adding phosphoric acid. The output of this process is refined kamani crude oil. In fact, since free fatty acid (FFA) of kamani oil is quite high (around 20%), esterification should be conducted before transesterification process. The materials used in the esterification process are 20% methanol (6.6 kg) and 2% sulfuric acid (0.66 kg). To continue the process to get kamani biodiesel, the next step is transesterification which uses 20% methanol (6.6 kg) and 1% sodium hydroxide (0.33 kg). Biokerosene can also be produced from the esterification process by washing and drying after esterification process is finished. But this study is focused on the production of kamani biodiesel; hence the process is not terminated at esterification to produce biokerosene, but continued further to transesterification. The outputs of this whole process are kamani biodiesel which is the main product and some other co-products like glycerol, shell, and press cake. Glycerol production is one-third of produced biodiesel and used for soap and cosmetics, whereas shell and press cake can be used again for energy. Press cake can be used for briquettes and in this process shells are burnt for steaming the seed.

In this whole production process of kamani biodiesel, fossil diesel is used for the machine and transporting the fruit from fruit collector to plant. For transportation, diesel as fuel with net heating value is 44.66 MJ/ kg (Prueksakorn and Gheewala, 2008) and for kamani biodiesel is 41.39 MJ/kg (Rahman et al, 2013). The distance between fruit collector place and plant is approximately 10 km and 1 ton of fresh fruit is carried per trip. This means in this case, to transport the amount of fresh fruit needed for 1 ton kamani biodiesel, the transporting should be done eight times. Other diesel consumption is in the fruit separation and pressing process, to run the machine for crushing the fruit for separation process which needs 2 liters diesel per 184 kg crude oil, whereas the seed pressing process consumes five times as much fossil diesel. Kamani biodiesel production process is shown in Figure 4.1 and the mass flow to produce 1 ton kamani biodiesel is shown in Figure 4.2. The inventory of crude oil production and biodiesel production are shown in Table 4.5 and Table 4.6.

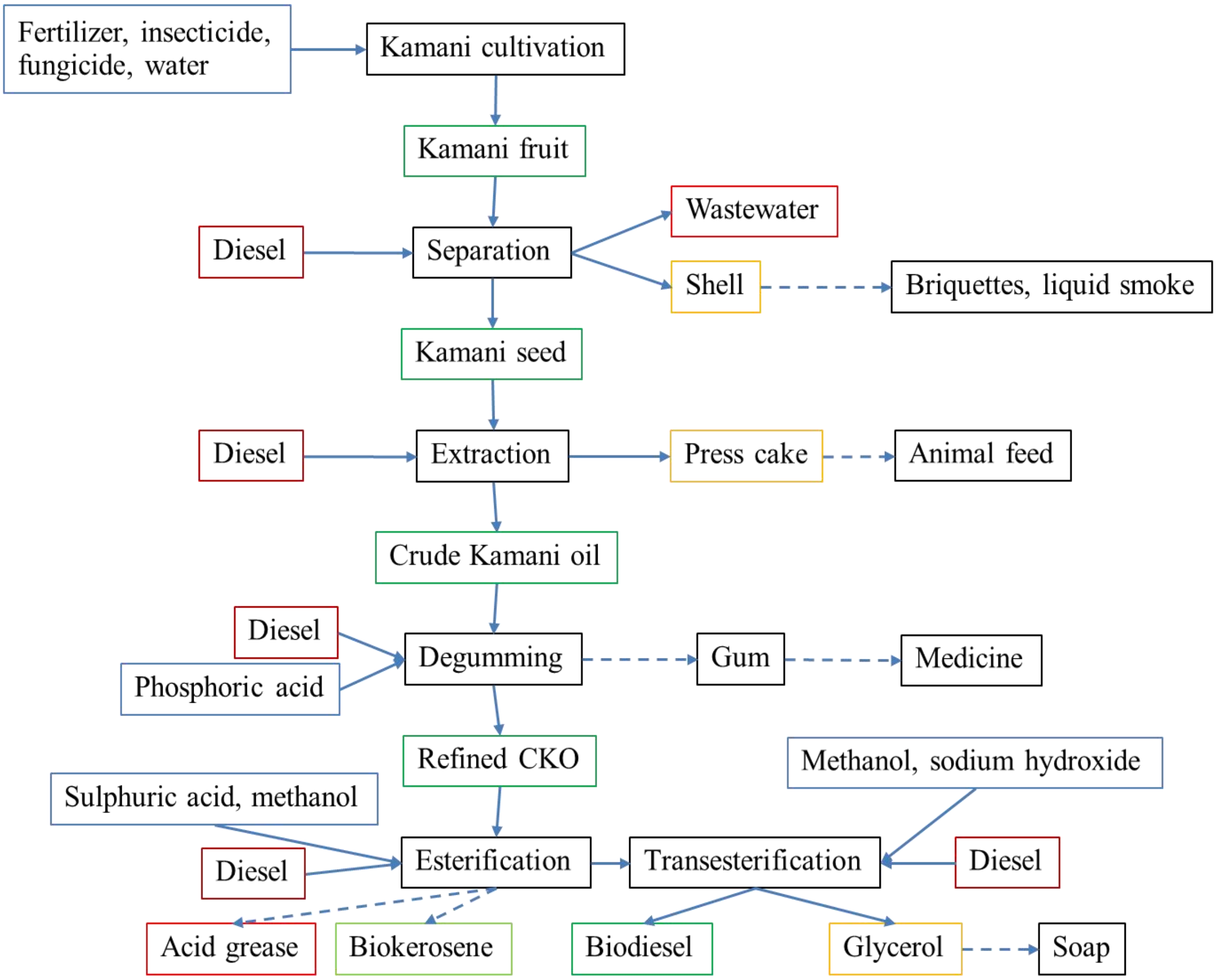

Figure 1.1 Kamani Biodiesel Production Process

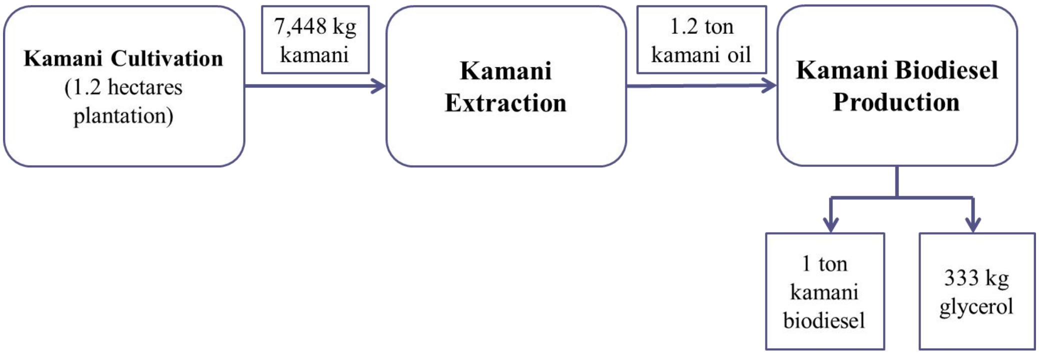

Figure 4.2 Mass Flow of Production of 1 ton Kamani Biodiesel

Table 4.5 Inventory of extraction of 1 ton kamani crude oil

	Item	Amount			Unit
INPUT	Phosphoric Acid	10			kg
ENERGY	Diesel for machine	65			kg
PRODUCT	Kamani Crude Oil	1000			kg
	Substance	Phosphoric Acid	Diesel for machine	Total	Unit
AIR EMISSION	CO_2	5.81E-01	2.06E+02	2.07E+02	g
	CO		5.11E+02	5.11E+02	g
	N_2O		9.00E+00	9.00E+00	g
	CH_4		2.15E+00	2.15E+00	g
	NMVOC		1.32E+02	1.32E+02	g
	NOx		1.90E+03	1.90E+03	g
	NH_3		5.22E-01	5.22E-01	g
	TPM	1.98E+00	6.37E+01	6.56E+01	g

4.4 Life Cycle Inventory of Production of 1 ton Kamani Biodiesel

Table 4.6 Inventory of Production of 1 ton Kamani Biodiesel

	Item	Amount					Unit
INPUT	Kamani Crude Oil	1.27					ton
	Methanol	508					kg
	Sodium hydroxide	12.69					kg
	Sulfuric acid	25.38					kg
ENERGY	Diesel for machine	41					kg
PRODUCT	Kamani Biodiesel	1					ton
	Glycerol	333					kg
	Press cake	1788					kg
	Substance	Methanol	Sodium hydroxide	Sulfuric acid	Diesel for machine	Total	
EMISSION	CH_4	4.97E-01	1.58E-05		1.37E+00	1.86E+00	g
	CO		3.30E-03		3.24E+02	3.24E+02	g
	CO_2	2.19E+05	3.68E-04		1.31E+02	2.19E+05	g
	N_2O		1.14E-04		5.71E+00	5.71E+00	g
	NH_3			3.30E-04	3.31E-01	3.31E-01	g
	NMVOC				8.36E+01	8.36E+01	g
	NOx	1.17E+02	2.97E-03	1.14E+01	1.20E+03	1.33E+03	g
	PM			8.88E-03	4.04E+01	4.04E+01	g
	SO_2	9.14E+00	2.35E-04	2.32E+02		2.41E+02	g
	SO_4			1.52E+01		1.52E+01	g

4.5 Life Cycle Energy

4.5.1 Energy Input and Energy Output

The functional unit of this study is 1 ton kamani biodiesel. Hence, the energy analysis was calculated based on the functional unit that was in MJ/ton kamani biodiesel. The energy analysis calculation of this study used a single tree as a reference flow; thus the input and output of kamani biodiesel was obtained for one tree for its economic life of 25 years. The amount of fruits per tree for 25 years economic life is 375 kg. The final calculation of energy analysis, however, is still based on the functional unit of this study which is 1 ton of kamani biodiesel which requires 7,448 kg fruit. Energy factors used in this calculation are the calorific values of the respective materials or products. The calculation result for inputs and outputs of kamani biodiesel are shown in Table 4.7.

Table 4.7 Energy inputs and outputs of kamani biodiesel

INPUT					**Energy Factor**
Kamani Cultivation	**Amount**	**Unit**	**Energy**	**Unit**	
NPK Fertilizer	3.81	kg	40.68	MJ	10.6 MJ/kg
Fungicide	0.0004	kg	0.04	MJ	92 MJ/kg
Diesel in transportation	0.033	L	1.47	MJ	44.6 MJ/L
Energy input for kamani cultivation			**42.19**	**MJ**	
Kamani Oil Production	**Amount**	**Unit**	**Energy**	**Unit**	
Phosphoric Acid	0.20	kg	6.48	MJ	32.6 MJ/kg
Diesel for machine	1.11	L	50	MJ	44.6 MJ/L
Energy input for kamani crude oil production			**56.48**	MJ	
Biodiesel Production	**Amount**	**Unit**	**Energy**	**Unit**	
Methanol	7.94	kg	240	MJ	30.27 MJ/kg
Sodium hydroxide	0.20	kg	4	MJ	18 MJ/kg
Sulfuric acid	0.40	kg	6	MJ	15 MJ/kg
Diesel for machine	0.65	L	29	MJ	44.6 MJ/L
Energy input for kamani biodiesel production			**279**	**MJ**	
TOTAL ENERGY INPUT			**377**	**MJ/tree**	
			7,493	**MJ/ ton KB**	
OUTPUT					**Energy Factor Source**
Item	**Amount**	**Unit**	**Energy**	**Unit**	
Kamani Biodiesel (KB)	50.35	kg	2,084	MJ	41.4 MJ/kg
Glycerol	16.78	kg	319	MJ	19 MJ/kg
Press cake	90.00	kg	2,339	MJ	25.9 MJ/kg
TOTAL ENERGY OUTPUT			**4,742**	**MJ/ tree**	
			94,182	**MJ/ ton KB**	

Total energy output for the whole life cycle of kamani biodiesel is 94,182 MJ per ton kamani biodiesel which is from,

The outputs of this whole process are kamani biodiesel, which is the main product and some other co-products such as glycerol, shell, and press cakes. Glycerol production is one-third of produced biodiesel and can be used for soap and cosmetics, whereas shell and press cake can be used for energy. Press cake can be used for briquette, and in this process, shells are burnt for steaming the seed.

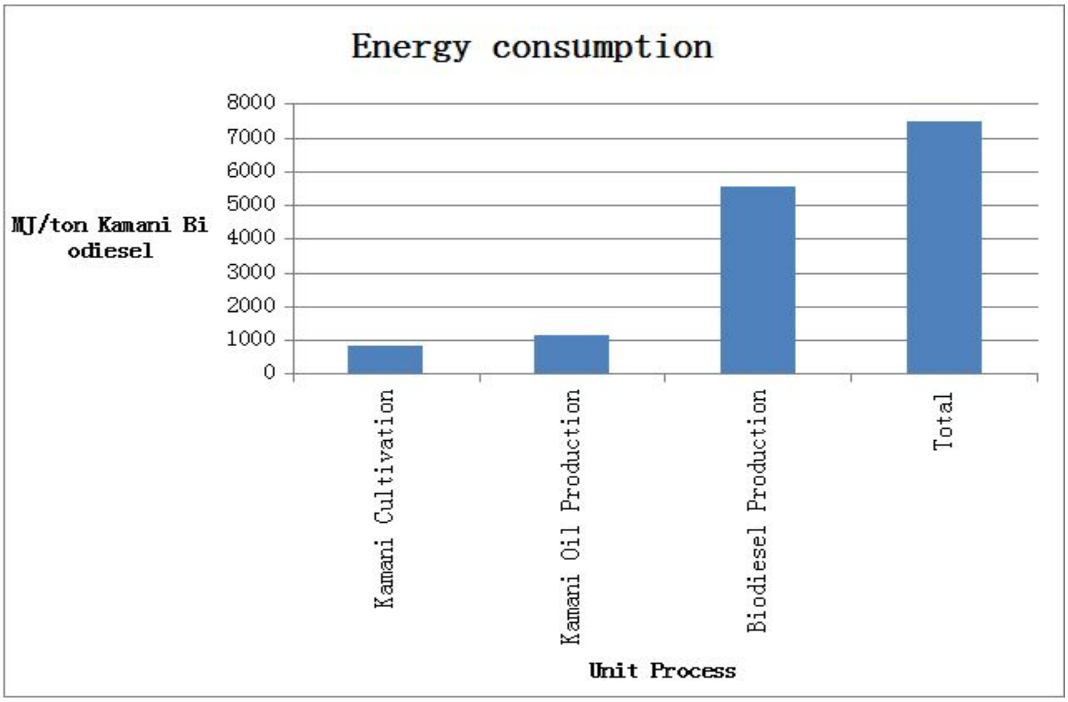

Figure 4.3 Energy Consumption of Life Cycle Kamani Biodiesel Process

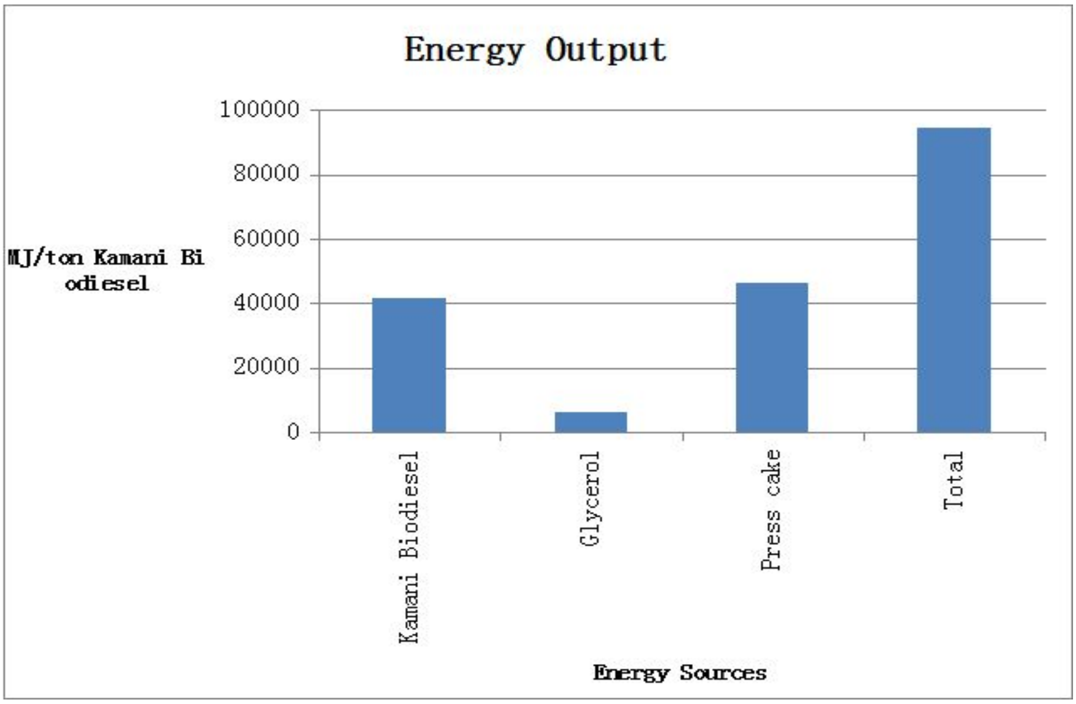

Figure 4.4 Energy Output of Life Cycle Kamani Biodiesel Process

Table 4.8 shows the comparison between kamani, palm and jatropha related to its cultivation and oil yield. Kamani has a lower oil yield than palm, but higher than jatropha. Energy analysis of biodiesel from palm oil was conducted by Pleanjai and Gheewala [3], the study also compared net energy balance per hectare of palm biodiesel to other various feedstocks, including Jatropha. From that study, net energy balance of Jatropha biodiesel is 11,800 MJ/ha/year (with co-products) where palm biodiesel is 3,034 MJ/ha/year (with co-products) and 2,220 MJ/ha/year (without co-products) [3]

. Kamani biodiesel has net energy balance for 4,676 MJ/ha/year (with co-products) and 2,055 MJ/ha/year (without co-products).

Table 4.8 Comparison between Kamani, Palm and Jatropha

	Kamani	Palm	Jatropha
Oil yield	1,375 kg oil/ha/year	3,500 kg oil/ha/year	400-500 kg oil/ha/year
Oil content	40 – 45%	40 – 50%	17.7 – 25.1 %
Trees per hectare	400 trees	140 trees	1,667trees
Minimum plantation time	7 years	3 years	5 years

(Sources: [29]; [30]; [31])

4.5.2. Net Energy Balance and Renewability Factor

The highest energy consumption from the whole life cycle of biodiesel was from biodiesel production because of the use of methanol. Nevertheless, the energy output of kamani biodiesel is higher than the inputs therefore, it shows that the process is efficient, the difference between output and input with co-products is 86,811 MJ/ton biodiesel and without co-products is 33,897 MJ/ton biodiesel, also referred to as the net energy balance (NEB). To know whether kamani biodiesel can be considered as a suitable substitute for fossil fuel can be seen from its renewability factor. The renewability factor should higher than 1; in this case for kamani biodiesel, the factor is 5.52 (kamani biodiesel only) and 12.57 (all products), this value indicates that kamani biodiesel is renewable and can help reducing dependence on fossil fuels.

4.6 Impact Assessment

Based on the ReCiPe method, impact assessments that are used in this study are climate change, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial acidification, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity and fossil depletion. These environmental impacts are caused by the emissions of CO_2, CO, NO_x, SO_2, CH_4, NH_3, and NVMOC. The impacts assessments categories only consider emissions that are classified in ReCipe method. The environmental impacts from three stages of kamani biodiesel process are shown in Figure 4.5. The highest emission contributor in each impacts are mostly from cultivation stage.

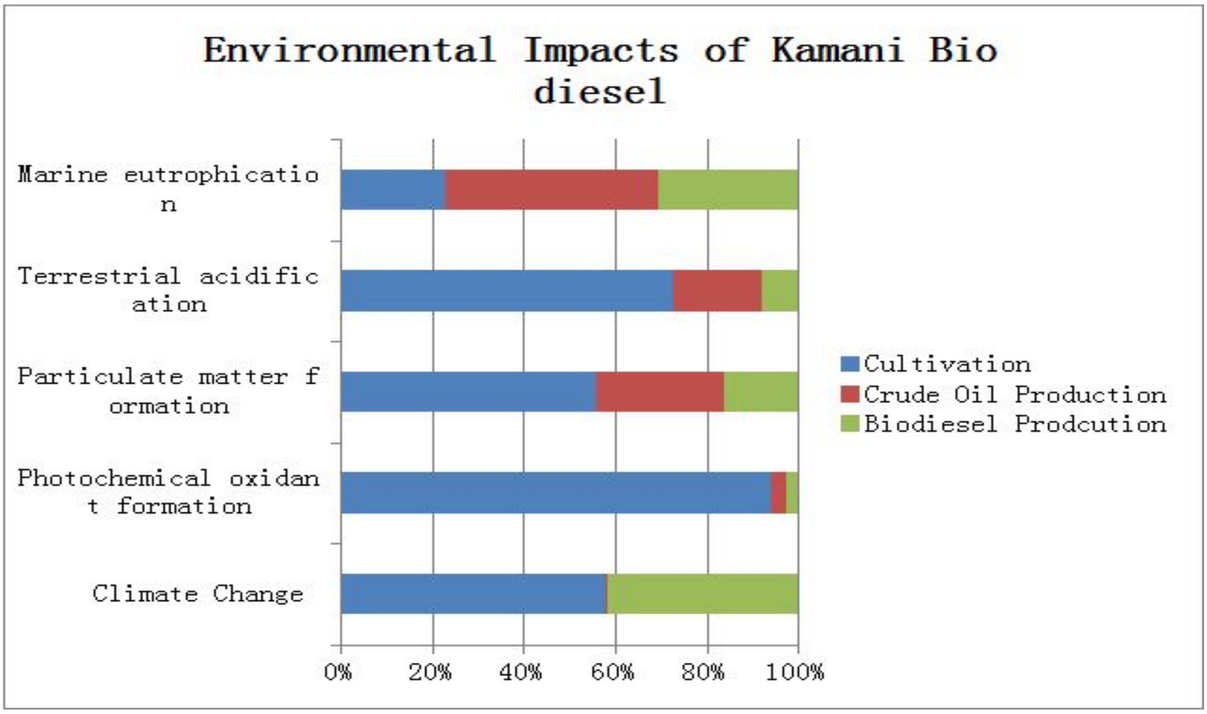

Figure 4.5 Environmental Impacts of 1 ton Kamani Biodiesel

4.6.1 Climate change

Climate change impacts of 1 ton kamani biodiesel from the three stages of the life cycle of kamani biodiesel which are cultivation, kamani crude oil production and kamani biodiesel production are shown in Figure 4.5. Total climate change that occurred from those stages is 529 kg CO_2-eq which is 57% from cultivation and 42% from biodiesel production, cultivation activity is the biggest emission contributor for this impact. This occurred because of the production and use of fertilizer during cultivation which are manure and NPK fertilizer.

Biodiesel production stage also contributed quite high emissions from methanol used in the transesterification process. The emission from crude oil production process is mostly from diesel use for machines. During this process, there are fruit and seed separation process also seed extraction that are done by machines. The machines are operated and fueled by fossil diesel which contributes greenhouse gases from its combustion.

The Global Warming Potential impact of palm biodiesel is 690 kg CO_2-eq [2], 2012), which is slightly higher than kamani biodiesel.

4.6.2 Terrestrial acidification

Figure 8 shows the terrestrial acidification impact assessment of 1 ton kamani biodiesel process and the total terrestrial acidification impacts assessment is 12.16 kg SO_2-eq which 72% of this value comes from cultivation stage. The major contributors are from ammonium and nitrogen oxides emitted from fertilizer production and fossil diesel for transport. Different from global warming potential/climate change of palm biodiesel which was higher than kamani biodiesel, its acidification 1.178 kg SO_2-eq [2] was much lower than kamani biodiesel. This happened because of the fertilizer use during cultivation.

4.6.3 Photochemical oxidant formation

Figure 8 shows the photochemical oxidant formation impact assessment of 1 ton kamani biodiesel process. As can be seen in the graph, the highest emission contributor is from the cultivation stage which was 94% from total photochemical oxidant formation impact assessment of 59 kg NMVOC. Those emission gases that were categorized in this impact assessment were CO, NOx, NMVOC, and SO_2.

4.6.4 Particulate matter formation

The particulate matter formation impact assessment of 1 ton kamani biodiesel is shown in Figure 4.5 where the highest contributor came from the cultivation stage, which is 56% of total value of this impact. The total particulate matter formation impact is 2.1 kg PM10-eq. The emission gases that were categorized in this impact are NH_3, NOx, and SO_2.

4.6.5 Marine eutrophication

Figure 4.5 shows marine eutrophication impact assessment of 1 ton kamani biodiesel. The total marine eutrophication impact is 1.69 kg N-eq where the biggest emission contributor came from crude oil production process and emission gases which 47% of total value. The emission gases that were categorized in marine eutrophication impact are NH_3 and NOx from fossil diesel use in machinery.

4.6.6 Human toxicity

The total environmental impact assessment of human toxicity for 1 ton kamani biodiesel process is 1.12×10^{-12} kg 1.4 DB-eq where the source of this impact came from fungicide so this impact occurred only because of the kamani cultivation stage. The toxic in fungicide is mancozeb.

4.6.7 Terrestrial ecotoxicity

The total environmental impact assessment of terrestrial ecotoxcity for 1 ton kamani biodiesel process is 6.3×10^{-8} kg 1.4 DB-eq where the source of this impact came from fungicide so this impact occurred only because of kamani cultivation stage. The toxin in fungicide is mancozeb.

4.6.8 Freshwater ecotoxicity

The total environmental impact assessment of freshwater ecotoxicity for 1 ton kamani biodiesel process is 1.84×10^{-8} kg 1.4 DB-eq where the source of this impact came from fungicide so this impact occurred only because of kamani cultivation stage. The toxin in fungicide is mancozeb.

4.6.9 Marine ecotoxicity

The total environmental impact assessment of marine ecotoxicity for 1 ton kamani biodiesel process is 4.54×10^{-11} kg 1.4 DB-eq where the source of this impact came from fungicide so this impact occurred only because of kamani cultivation stage. The toxin in fungicide is mancozeb.

4.6.10 Fossil depletion

Total environmental impact of fossil depletion is 120 kg oil-eq where the highest contribution was from crude oil production stage. It happened because of the use of fossil diesel to operate the machine for seed extraction. Value from each stage of 1 ton kamani biodiesel production process is shown in Figure 4.6.

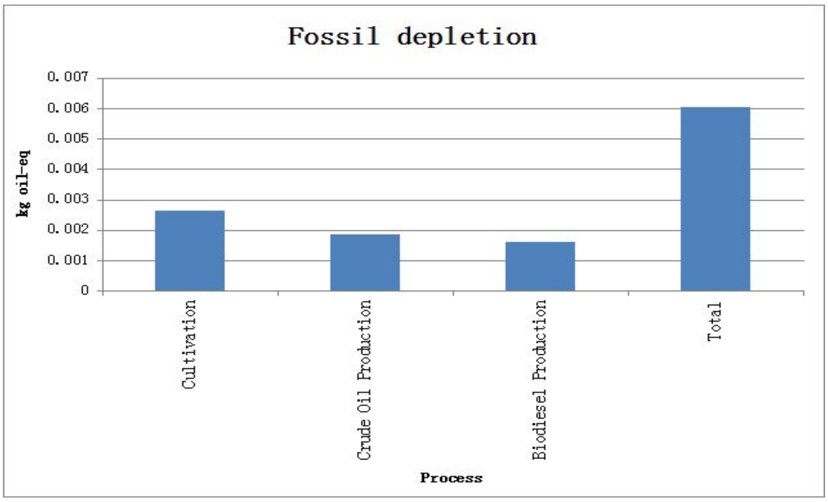

Figure 4.6 Life Cycle Impact of Fossil Depletion of Kamani Biodiesel Process

4.7 Life Cycle Cost

The economic performance of kamani biodiesel can be identified by calculating the life cycle costs (LCC). The life cycle costs of kamani biodiesel production in this study was determined by including all costs in the production system such as kamani cultivation, crude oil production, biodiesel production and all fossil fuels used for machinery and transport. The life cycle costs of kamani biodiesel production include feedstock costs, capital costs, operating costs and transportation costs. In this study, prices in the year 2014 were chosen as the base year for analyzing, converted by using Indonesian Consumer Price Index (CPI). The comparison of cost performance between kamani biodiesel and fossil diesel is done as well.

4.7.1 Kamani Biodiesel Production Cost

In this study, the cultivation costs of kamani are land preparation costs (labor wage), planting costs (including seed, plastic bag and planting equipment), chemicals (fertilizer and fungicide), harvesting and transportation of seed, fertilizer and fungicide. The total production costs from plantation to factory is 804,570 per ton kamani fruit. Collected kamani fruits are sold for Rp 1,000/kg and for 1 ton kamani fruit is Rp 1,000,000, the kamani fruit collector benefit is Rp 195,430 per ton kamani fruit. The amount of kamani cultivation cost is shown in Table 4.9.

Table 4.9 Cultivation costs to harvest 1 ton of kamani fruit

	Amount	Unit	Costs	
Land preparation	10 labors	20,000 Rupiah/liter	200,000	Rupiah
Planting: Plastic bag Paranet Labors	 4 packs 5 meters 5 labors	 26,000 Rupiah/pack 20,000 rupiah/meter 20,000 Rupiah/labor	 104,000 100,000 100,000	 Rupiah Rupiah Rupiah
Manure	133 kg	2,010 Rupiah/kg	267,400	Rupiah
NPK Fertilizer	6 kg	2,800 Rupiah/kg	16,800	Rupiah
Fungicide	0.02 gr	30,000 Rupiah/gr	600	Rupiah
Transportation	1.66 liter	7,500 Rupiah/liter	12,450	Rupiah
		Total	801,250	Rupiah
		Sale Price	1,000,000	Rupiah
		Farmer Income	198,750	Rupiah

The costs of kamani biodiesel production are from the use of fossil diesel to run the machine and chemicals used during transesterification. The detail of kamani biodiesel costs are shown in Table 4.10. The highest cost during kamani biodiesel production process is from the use of fossil diesel in machinery.

Table 4.10 Conversion costs of 1 ton kamani biodiesel

Chemicals	Amount	Unit Cost	Costs	
Methanol	0.4 liter	13,750 Rupiah/liter	5,500	Rupiah
Sodium hydroxide	0.01 liter	25,000 Rupiah/liter	250	Rupiah
Sulfuric acid	0.02 liter	13,000 Rupiah/liter	2,600	Rupiah
Phosphoric acid	0.01 liter	65,000 Rupiah/liter	650	Rupiah
Diesel	79 liter	7,500 Rupiah/liter	592,500	Rupiah
Total			601,500	Rupiah

4.7.2 External Costs of Kamani Biodiesel

The environmental burden of kamani biodiesel should be included to get the external costs. The factor of external costs is obtained from the EPS model [32] which is presented per emission category. Environmental burden is taken from this study and the results of it are used for calculating willingness to pay (WTP). The formula used for calculating WTP of Indonesia [21], as below:

The GDP per capita in Indonesia ($PercapGDP\ (PPP)_{Indonesia}$) and GDP per capita in Sweden ($PercapGDP\ (PPP)_{Sweden}$) are obtained from CIA [33] and it is converted into rupiah (Rp) [34]. The calculation is shown in Table 4.11.

Table 4.11 External Costs per Environmental Burden Categories

Categories	Unit	WTP Sweden		WTP Indonesia
		Euro/unit	Rp/unit	Rp/unit
CO_2	kg	0.108	1,626	371
NO_X	kg	2.13	32,065	7,317
SO_2	kg	3.27	49,227	11,233
CO	kg	0.331	4,983	1,137
NMVOC	kg	2.14	32,216	7,351
PM10	kg	36	541,944	123,665
Fossil oil	kg	0.507	7,632	1,742

Table 4.12 External Costs of 1 ton Kamani Biodiesel and Palm Biodiesel

Categories	External Cost (Rupiah)		External Cost (Rupiah)	
	Amount (kg)	Kamani Biodiesel	Amount (kg)	Palm Biodiesel
CO_2	225.28	83,577	418	155,224
NO_X	4.18	30,555	3.52	25,769
SO_2	0.2618	2,941	0.671	7,540
CO	0.9242	1,051	0.410	467
NMVOC	0.2724	2,002		
PM10	0.106	13,108		
Fossil oil	107.66	187,502	11.5	20,040
	TOTAL	320,737		209,040

The result of kamani biodiesel external costs is shown in Table 4.12 which is Rp 320,737/ ton kamani biodiesel and the external costs for palm biodiesel is Rp 209,040/ton palm biodiesel.

Table 4.13 and 4.14 show total production costs of 1 ton kamani biodiesel with and without external costs. The price of feedstock and chemicals used are included in the total production costs.

Table. 4.13 Total production costs of 1 ton kamani biodiesel without external costs

	Costs	
Feedstock (7.448 ton)	7,448,000	Rupiah
Chemicals	601,500	Rupiah
Total	8,049,500	Rupiah

From the table above, price per liter of kamani biodiesel can be obtained by knowing kamani biodiesel density which is 0.87 kg/liter. The price of 1 liter kamani biodiesel without external costs is 7,003 rupiah. The calculation is shown as below,

Table 4.14 Total production costs of 1 ton kamani biodiesel with external costs

	Costs	
Feedstock (7.448 ton)	7,448,000	Rupiah
Chemicals	601,500	Rupiah
External Costs	320,737	Rupiah
Total	8,370,237	Rupiah

The price of 1 liter kamani biodiesel with external cost is 7,282 rupiah which is calculated as below, In comparison with palm biodiesel, the market price index is 8,000 rupiah/liter [35]. Even without external costs included, the price of palm biodiesel per liter is slightly higher than kamani biodiesel price.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

In Indonesia, the most commonly produced biodiesel is from palm oil, which its plantation is extended from year to year because of higher demand and profit makes it a good business. No matters how much it results a lot of environmental releases and issues, companies in southeast Asia especially Indonesia and Malaysia keep doing it. This study is conducted to answer that problems and suggest another alternative feedstock for biodiesel which is kamani (*Calophyllum inophylum L.*). The study considered the environmental impacts and energy analysis from all the life cycle process to produce biodiesel including kamani plantation stage, transportation to the production unit, kamani oil production stage, and biodiesel production stage.

Based on the analysis done, it could be concluded that the major contributors of climate change is from the use of fertilizer during cultivation and the use of methanol for the transesterification process. This biodiesel production used more methanol because there are esterification and transesterification processes.

Energy analysis has been done by calculating the net energy balance (NEB) and renewability factor. Both were used as factors for consideration of whether kamani biodiesel has energy efficiency or not. This study concluded that kamani biodiesel has renewability factor which is more than 1 and energy output is higher than input. It means that kamani biodiesel can be an alternative energy that could replace fossil diesel and reduce dependency on it. The difference between output and input with co-products is 86,811 MJ/ton biodiesel and without co-products is 33,897 MJ/ton biodiesel and the renewability factor of kamani biodiesel is 5.52 (kamani biodiesel only) and 12.57 (all products). This study also calculated LCC and external cost of kamani biodiesel production and its result is the total production cost of kamani biodiesel per liter is Rp 7,003 without external cost and Rp 7,282 with external cost.

From this study, it can be concluded that kamani biodiesel has fewer environmental impacts when compared to palm biodiesel and also has cheaper production costs. The reason why kamani is not famous or well developed as palm might be because still few people know or notice about this plant so there is still little research done about its cultivation, productivity and utility. The lack of long-term research about producing biodiesel from kamani makes government or company still doubt about this plant. Besides that, palm is currently more popular because it attracts more investment, and it also can be sold as food. To develop kamani as an alternative energy source, there should be continuous support from stakeholders and sustainable pilot projects in producing and using it.

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