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# Comparative Life Cycle Assessment of the Use of Coconut Biodiesel Blends and Neat Diesel in Public Utility Jeepneys in Metro Manila, The Philippines

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**Abstract:** This study aims to compare the $CO_2$ emissions from conventional diesel and coconut biodiesel blends from raw material extraction up to use as fuel for public utility jeepneys (PUJs) in the Philippines. This work used the process-based LCA approach with 1 kilometer distance travelled by PUJs as the functional unit. The kg $CO_2$ emissions from coconut farming and harvesting until the use phase of the coconut biodiesel blends in Metro Manila jeepneys were estimated in this work. The calculated emission factor of Coconut Methyl Ester (CME) from its fatty acid composition is 2.5539 kg $CO_2$ per 1 kg CME. The total $CO_2$ emissions in the life cycle of 2% CME blend (B2) and 5% CME blend (B5) were lower by 0.767% and 5.37%, respectively, compared to those from life cycle of neat diesel. In the life cycle of neat diesel, B2 blend, and B5 blend, the use phase contributed 75-78% of the $CO_2$ emissions. The kg $CO_2$ emissions from Metro Manila public utility jeepneys decreased from 0.400kg/km using neat diesel to 0. 381 kg/km and 0.363 kg/km using B2 blend and B5 blend, respectively. In the life cycle of coconut biodiesel from raw material extraction to CME production, 52-58% of $CO_2$ emissions come from the production of material inputs to the trans-esterification process. Three main recommendations are proposed by this work: (1) Extend the LCA to higher blend percentage. This entails measurement of specific fuel consumption of jeepneys using this fuel. (2) Increase engine efficiencies of Public Utility Jeepneys to reduce fuel consumption and realize higher $CO_2$ emission reductions. (3) Further studies on optimization of mole ratio of methanol to coconut oil in trans-esterification process must be done. Explore use of methanol from sources-other than natural gas- with less $CO_2$ emissions.

**Keywords:** CO2 emissions, coconut biodiesel, neat diesel, Public Utility Jeepneys.

## 1. Introduction

The transportation industry in the Philippines is the largest user of energy, making up 37.7 percent of the overall energy use [1]. The energy used by this sector mainly comes from petroleum products such as diesel, gasoline, and aviation fuel. The high energy needs of this sector arise from a significant dependence on road transport, which accounts for approximately 79.3 percent of the total fuel use in the industry [2]. The road transport part of the sector makes up 90% of all passenger travel and 50% of freight movement across the country, especially in urban locations like Metro Manila, due to an increasing number of passenger vehicles. There are 60,000 jeepneys, 4,000 buses, and 200,000 tricycles operating on the roads [3]. The Presidential Task Force on Climate Change indicates that the energy sector, which includes transportation, is the primary source of the Philippines' greenhouse gas (GHG) emissions, contributing 30% [4].

The Philippine Biofuels Act (RA 9367) mandated the use of bioethanol and biodiesel blends to reduce dependence on imported oil and to reduce GHG emissions. For biodiesel, the blend requirement started with 1% biodiesel in 2007 and was increased to 2% in 2009. The blend was planned to increase to 5% in 2015 [5]. Although this increase in blend percentage has not yet been fully realized due to coconut biodiesel supply issues, there are still calls from the Philippine Coconut Authority to the National Biofuels Board to raise the percentage of Coconut Methyl Ester (CME) to 5%. On the other hand, 68/82 provinces of Philippines are growing coconut. However, poverty is most widespread in provinces where coconut farming is the main source of income. Because of this, there is a need to assess the environmental implications of using coconut biodiesel blends using the LCA approach. In this work, biodiesel refers to ME, and biodiesel blend refers to mixture of CME and neat diesel.

The research carried out its evaluation by collecting information from the operations of public utility jeepneys situated in Metro Manila in the Philippines as shown in Figure 1 [6]. Metropolitan Manila, often referred to as Metro Manila and officially known as the National Capital Region (NCR), is the capital area and the biggest metropolitan region in the Philippines. Positioned on the eastern side of Manila Bay, the area is located between the Central Luzon and Calabarzon regions. Covering an area of 636.00 km2 (245.56 sq mi) and with a population of 13,484,462 as of 2020 [7], it is made up of sixteen highly developed cities: the capital city, Manila, Caloocan, Las Piñas, Makati, Malabon, Mandaluyong, Marikina, Muntinlupa, Navotas, Parañaque, Pasay, Pasig, Quezon City, San Juan, Taguig, and Valenzuela, in addition to one independent municipality, Pateros. As the second most populated and the most crowded region in the Philippines, it holds the 9th position as the most populated metropolitan area in Asia and the 6th position for the most populated urban area globally.

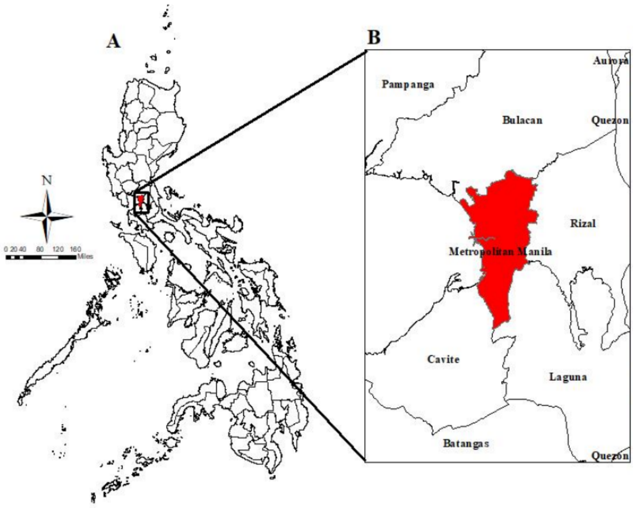



**Figure 1.** A) The location of Metro Manila. B) The provinces in Metro Manila

A jeepney, as the Figure 2, is a kind of public transport vehicle that is the most common way of getting around in the Philippines. Famous for its packed seating and colorful decorations, it is a cultural symbol of the Philippines and has its own form of art, known as Jeepney art. At the 1964 New York World's Fair, a Sarao jeepney was displayed in the Philippine section as a national emblem for Filipinos. Jeepneys trace their roots back to the American colonial era, originating from share taxis called auto calesas, usually shortened to AC. These developed into altered imported cars with added carriages in the 1930s, which acted as affordable passenger transport in Manila. Many of these vehicles were destroyed during World War II. The demand for new transport vehicles led to using U.S. military jeeps that remained after the war, which formed the basis for the modern jeepney. A jeepney modernization project started by the

Department of Transportation in 2017 aims to use greener vehicles, but has raised worries about keeping the jeepney's distinctive style, as newest jeepneys look like regular minibuses. As of 2022, around 600,000 drivers across the nation relied on driving jeepneys for their income [8]. In Metro Manila, approximately 9 million people use the jeepney every day [9].

**Figure 2.** Jeepneys on the road (Captured by Le Phu Tuan, 2019)

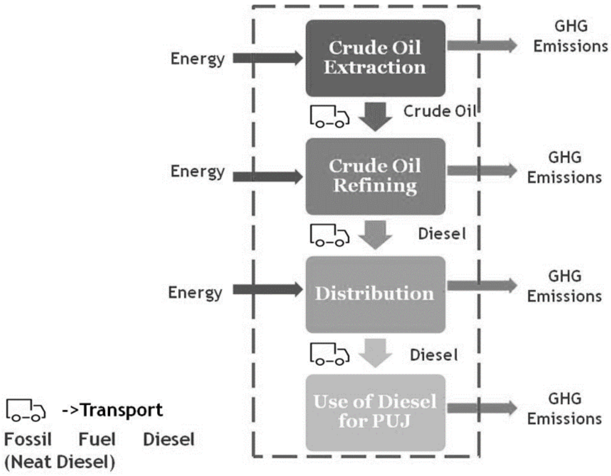



**Figure 3.** Life Cycle of Neat Diesel (Until Use Phase)

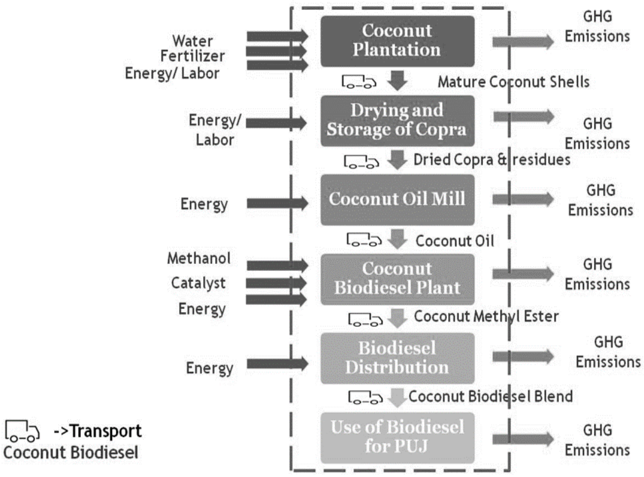



**Figure 4.** Life Cycle of Coconut Biodiesel Blend (Until Use Phase)

The system boundary includes the $CO_2$ emissions from the life cycle stages shown in Figures 3 and 4 for neat diesel and biodiesel blends, respectively. For neat diesel, the stages include crude oil extraction, crude oil refining, and distribution. For biodiesel, the stages include farming and harvesting of coconut, copra processing, production of coconut oil, production and purification of coconut methyl ester, and biodiesel blend distribution. For both neat diesel and coconut biodiesel, the GHG emissions from transportation of intermediate products and products are also accounted. The system boundaries are indicated by the dashed liens in Figures 3 and 4.

The results of this assessment are intended for use of policy makers, researchers, coconut farmers, coconut oil and coco methyl ester producers, and coconut biodiesel consumers.

Process Flow for **Neat Diesel** is described in Figure 3.

**Crude Oil Extraction:** This includes the upstream processes including extraction from the reservoir, surface processing and transport in pipelines.

According to Department of Energy, all crude oil brought in for the first half of 2022 was entirely sourced from the Middle East, with 56.79 percent coming from Saudi Arabia (1,416 ML), which is the main supplier of crude oil for the country. This was followed by the UAE, contributing a 22.59 percent share (563 ML). Crude oil from Iraq made up 17.42 percent, while the last 3.2 percent was imported from Qatar (80 ML) [10]. After arriving in the Philippines, crude oil will be processed by local refineries for different needs of customers.

**Crude Oil Refining:** This includes refining of crude oil into different petroleum products including diesel.

**Distribution and Use:** After diesel production from crude oil refining, it is transported from refinery to oil storage depots and then products are distributed from oil storage depots to refueling stations.

The diesel will then be dispensed for use as fuel for Public Utility Jeepneys.

**Transport:** The $CO_2$ emissions from transport of products and interim products were also included in this study.

Process Flow for **Coconut Biodiesel** is described in Figure 4.

**Coconut Farming:** Greenhouse gas emissions in coconut farming come from fertilizer application to coconut seedlings in the nursery. When the coconut seedlings have grown, the mature coconut fruits are harvested by hand.

**Copra Processing:** Mature coconut fruits are de-husked manually. De-husked coconuts are split to separate the coconut water. The coconut shells and meat are then dried and reduced to size prior feeding to coconut oil expellers.

**Coconut Oil Production:** Dried and size-reduced copra is fed to expellers to extract the coconut oil. The coconut oil produced is then settled, filtered, and stored prior use or transport to downstream processes.

**Biodiesel Production and Purification:** The coconut oil is transformed to coconut oil methyl ester through trans-esterification. This occurs through reaction of coconut oil with methanol, aided by a catalyst. In this study, the catalyst chosen is KOH. This happens in a reactor unit [11].

The equation in the Figure 5 shows the general reaction of triglycerides (vegetable oils) and methanol to form fatty acid methyl esters [12].

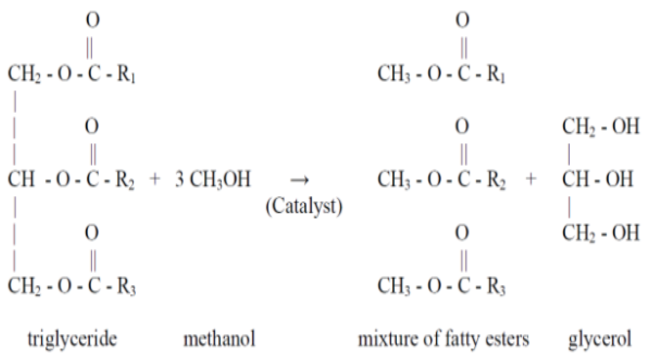



**Figure 5.** Trans-esterification reaction

After trans-esterification, glycerin is separated from the coconut methyl ester in a settling unit where layering, washing, and drying occurs. This is considered the purification process of the coconut methyl ester.

The following Figure 6 shows the diagram of a pilot-scale biodiesel production plant designed by Hewa Walpita et al. (2012) which is also applicable for coconut methyl ester production [11].

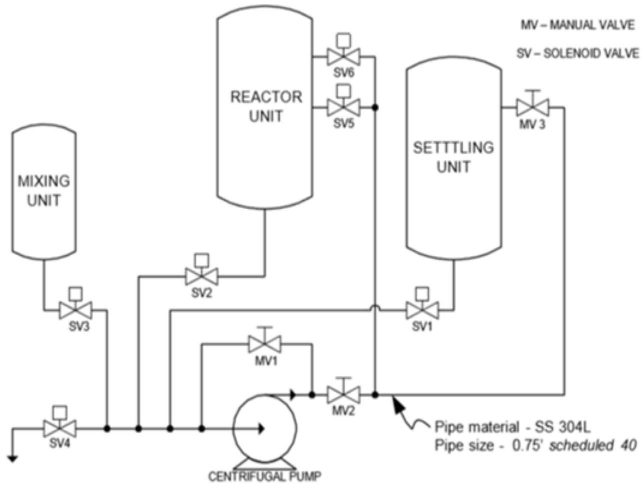



**Figure 6.** Diagram and Components of the Biodiesel Production and Purification Stage

**Distribution and Use Phase:** Purified CME is then transported from the CME plant to refueling stations, where the CME blends will be dispensed as fuel for automotive vehicles such as jeepneys.

**Transport:** The $CO_2$ emissions from transport of products and interim products were also included in this study.

This study aims to provide a comprehensive comparative life cycle assessment (LCA) of the environmental impacts of using coconut biodiesel blends versus neat diesel in public utility jeepneys (PUJs) in Metro Manila, the Philippines. Specifically, the research evaluates key environmental indicators, including greenhouse gas (GHG) emissions, energy consumption, and air pollutant outputs across the entire fuel life cycle. Unlike previous studies that focused primarily on the tailpipe emissions of biodiesel use, this work adopts a cradle-to-grave approach, encompassing raw material extraction, fuel production, distribution, and utilization phases. Moreover, this study uniquely examines the performance of coconut-based biodiesel, a renewable resource abundant in the Philippines, in the context of urban public transport—a sector that significantly contributes to local air pollution and carbon emissions. By highlighting the potential trade-offs and benefits of transitioning to biodiesel blends, this research aims to inform policymakers and stakeholders about sustainable fuel alternatives tailored to the country's specific context and resource availability.

## 2. Methods

**Life Cycle Assessment Framework:**

The study adopted a Life Cycle Assessment (LCA) approach to evaluate and compare the environmental impacts of using coconut biodiesel blends (e.g., B2, B5) and neat diesel. The LCA process adheres to established standards, with ISO 14040 and ISO 14044 providing a robust framework for LCA methodology (ISO, 2006a, 2006b). The LCA framework included four main phases:

**Goal and Scope Definition:** Setting the study boundaries to include all relevant stages from resource extraction, production, and transportation to fuel combustion.

**Life Cycle Inventory (LCI):** Compiling detailed data on inputs (raw materials, energy) and outputs (emissions, waste) for each stage.

**Life Cycle Impact Assessment (LCIA)**: Quantifying environmental impacts, particularly focusing on $CO_2$ emissions.

Interpretation: Analyzing results to draw conclusions and provide actionable insights.

**System Boundaries:**

The system boundaries included the entire lifecycle of the fuels:

- For coconut biodiesel blends: Coconut farming, oil extraction, biodiesel production (transesterification), distribution, and combustion in jeepney engines.
- For neat diesel: Crude oil extraction, refining, distribution, and combustion.

**Data Collection:**

- Primary Data: Collected from local sources, such as coconut farms (10 farms) and biodiesel production facilities (4 facilities) in Metro Manila, the Philippines, focusing on inputs and outputs of the production process. Data were collected primarily through interviews, reports from owners and from Department of Energy, Republic of the Philippines.
- Secondary Data: Sourced from literature, databases, and government reports for energy inputs, emission factors, and material use, particularly for diesel production and consumption.

**Fuel Blend Scenarios:**

The study examined neat diesel and coconut biodiesel blends (B2 and B5), representing mixtures of 2% and 5% CME with conventional diesel.

**Emission Calculations:**

Tailpipe emissions from fuel combustion in jeepneys were calculated based on standard emission factors and vehicle operating conditions typical for Metro Manila.

Emissions from upstream processes, including coconut farming and biodiesel production, were estimated using secondary data and calculation process.

$CO_2$ from road transport

$$\text{Emission} = \sum_a [\text{Fuel}_a \cdot \text{EF}_a] \qquad \text{(equation 1)}$$

where Emission = kg $CO_2$ / km

Fuel = amount of fuel per distance travelled, kg/km

EF = emission factor, equal to the carbon content of fuel multiplied by 44/12, kg $CO_2$/ kg fuel

a = type of fuel.

Although the main attention is often on carbon dioxide, there are additional gases that add to this greenhouse effect like methane and nitrous oxide.

To figure out how much each gas contributes, there is a measure known as Global Warming Potential that contrasts the warming ability of a specific amount of these greenhouse gases with the warming ability of the same quantity of carbon dioxide, allowing the impact of these various gases to be assessed using a consistent measurement unit, known as $CO_2$ equivalent. Thus, the following equation is applied to compute greenhouse emissions:

GEI (t $CO_2$e) = GEI ($t_{fuel}$)*$GWP_{fuel}$ (quation 2)

The calculation process and results will be presented in detail in the following section.

## 3. Results and discussion

### 3.1. Formulating a LCA calculation process

This study adhered to the ISO 14040 (Environmental Management – Life Cycle Assessment – Principle and Framework) and 14044 (Environmental Management – Life Cycle Assessment – Requirements and Guidelines) standards, covering mainly inventory analysis of $CO_2$ emissions for life cycle phases of coconut biodiesel blends and neat diesel intended for use as fuel for public utility jeepneys in Metro Manila.

The following sections discuss the inputs and outputs considered, general assumptions and calculations for estimating $CO_2$ emissions.

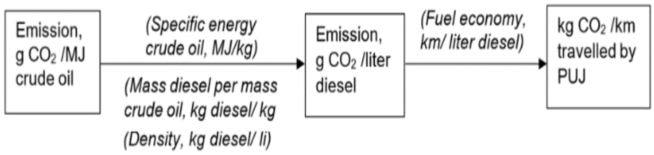
#### 3.1.1. Life Cycle Inventory for Neat Diesel (100% Fossil Fuel Diesel)

**Crude Oil Extraction:** For the inventory in crude oil extraction, the emissions from the following upstream processes were included: extraction from reservoir, surface processing and pipeline transport. The following data on $gCO_2$ eq per MJ of crude oil was obtained from a study by European Commission on 2014 [13].

**Table 1**. Energy consumption and emissions in crude oil upstream processes

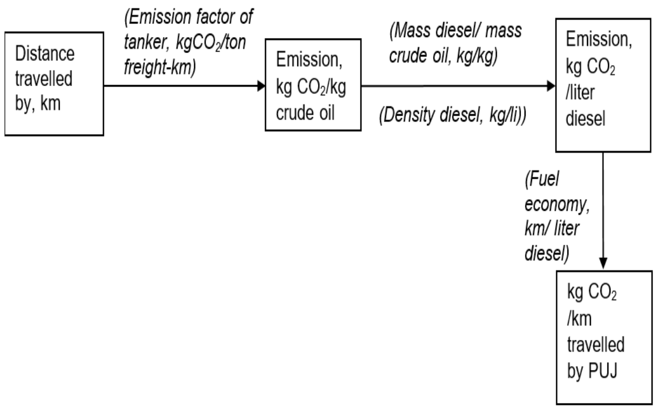
| | | | |
|---|---|---|---|
| Crude oil extraction | Total energy consumption | MJ/MJ | 0.012 |
| | Total GHG emission | $gCO_2eq/MJ$ | 0.94 |
| Surface processing | Total energy consumption | MJ/MJ | 0.046 |
| | Total GHG emission | $gCO_2eq/MJ$ | 4.74 |
| Crude oil transport in pipelines | Total energy consumption | MJ/MJ | 0.013 |
| | Total GHG emission | $gCO_2eq/MJ$ | 0.94 |

To convert this data to the LCI result kg $CO_2$ per kilometer of distance travelled by PUJ, the data on specific energy of crude oil, yield, density of diesel and fuel economy were used.

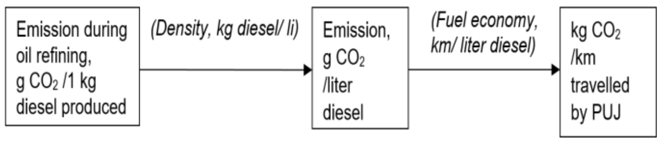



**Crude Oil Transportation to Philippines:** Based on the assumption that 99.99% of crude oil is imported from Middle East, the distance from Saudi Arabia to the Philippines was used in the calculations. This is a roundtrip distance of 16,400 km. The mode of transport of crude oil is via a 200,000 tons ocean tanker, which is a regular type of fuel tanker across the ocean. The emission factor of this tanker is 0.0029 kg/(ton freight-km).

To calculate kg $CO_2$/km distance travelled by PUJ, attributed to this life cycle stage, the following scheme is used:



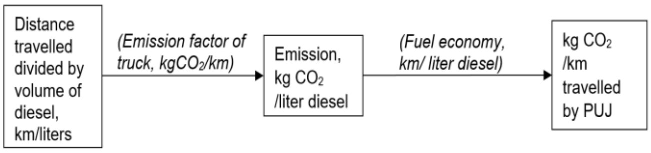

**Crude Oil Refining:** A study by Sheehan et al on the life cycle assessment of petrol diesel showed that 360.4 g $CO_2$ is emitted per 1 kg diesel produced during oil refining.




**Diesel Transport to Refueling Stations:**

In calculating the average distribution distance for the local diesel consumption in distribution, the Petron Bataan Refinery in Limay, Bataan was chosen as refinery/depot for supplied diesel for refuel stations. The average distance from refinery/depot to refuel stations is 344km (roundtrip). It was assumed that diesel was distributed by fuel tank truck with 20,000 liter of load with emission factor of this heavy truck in Manila was 800g$CO_2$eq./km [14].

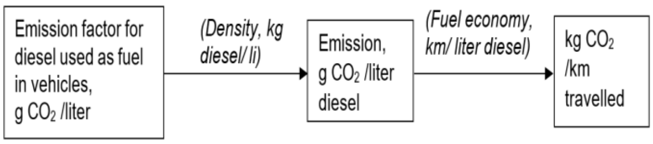
The following scheme was used in the calculations:




**Diesel Distribution:** The $CO_2$ emissions from the operation of gasoline station were considered negligible. The locations of refueling stations were assumed to be along the route of the jeepney. This is the basis of the emissions from transport of jeepney to refueling station equal to zero.

**Diesel Use in Public Utility Jeepneys:** The emission factor was already obtained from Carbon Dioxide Emissions Coefficients (2016) listed by US Energy Information Agency. The emission factor used is 2.68 kg $CO_2$/ liter diesel used as fuel in vehicles [15].

The fuel consumption was obtained from a road-test on jeepneys with 65% load in Metro Manila by Quiros et al. (2017). The fuel consumption used is 6.7 km/liter diesel [16].




### 3.1.2. Life Cycle Inventory for Coconut Biodiesel Blend

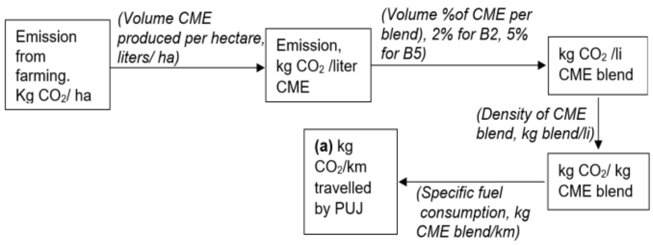
**Inputs and outputs:** Life cycle inventory inputs included material and energy, while inventory outputs included GHG emissions, copra, coconut oil, coconut biodiesel. These inputs and outputs were previously shown in Figures 3 and 4.

**Coconut Farming:** The following data on greenhouse gas emissions during coconut farming per hectare were obtained from a life cycle assessment on CME production. In this study, the amount of CME produced is 1319.91 liters per hectare of coconut farm [17].

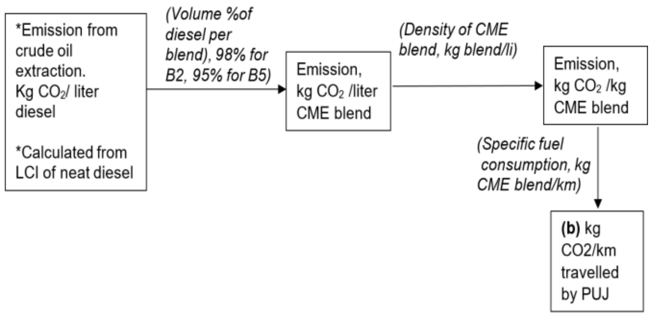
**Table 2**. $CO_2$ emissions during coconut farming per hectare

| Activity | kg $CO_2$ eq/ha |
|---|---|
| Nursery | 17.47 |
| Cultivation | 89.48 |

The following scheme was used to calculate the $CO_2$ emissions from the CME content of the biodiesel blend:



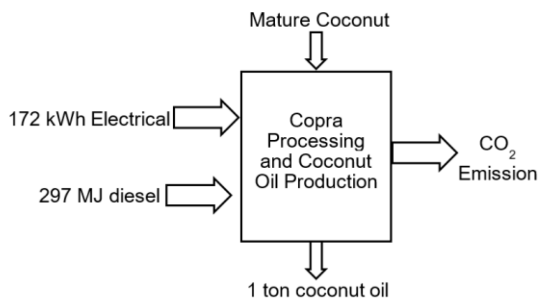

To calculate the kg $CO_2$ emissions from the diesel content of the blend, the following outlines the solution:




The total $CO_2$ emissions for the raw material extraction phase was obtained by adding $CO_2$ emissions associated with the CME and diesel contents of the blend **[(a) and (b)].**

**Copra Processing and Coconut Oil Production:** $CO_2$ emissions for copra processing and coconut oil production are lumped. Copra Processing and Coconut Oil Mill are assumed to be in the same location.

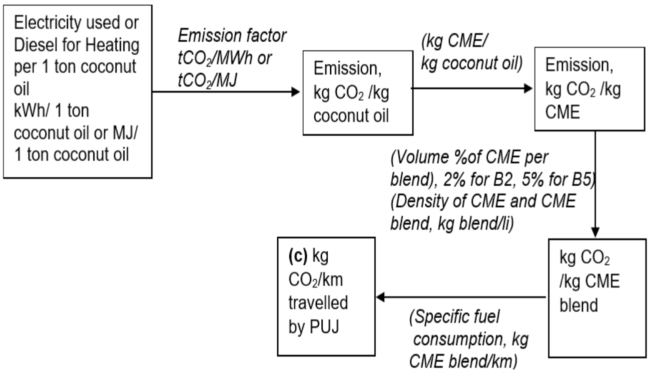
The following data on the energy consumption to produce 1 ton of coconut oil for Philippine set up was obtained from a study by Zah and Hischier in 2007 [18].




To convert these data to kg $CO_2$ emissions emitted, the following emission factors were used: The National Grid Emission Factor for Luzon-Visayas grid at 0.5979 tons $CO_2$/ MWh and the emission factor for diesel for heating at 74.10 tons

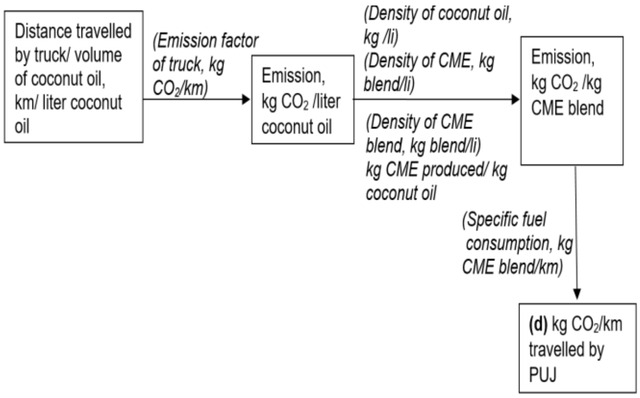
$CO_2$/TJ. The data on yield of 1 kg CME and 0.111 kg glycerin per 0.8457 kg coconut oil was also used [19].

The following solution outline was used to convert to the LCI result, kg $CO_2$/km travelled by PUJs.




**Transport of Coconut Oil to Coconut Methyl Ester Plant:** The average roundtrip distance of coconut oil mill to coconut methyl ester plant is 226 km. This distance is based on the distance from coconut farm/oil mill to CME plants in Lucena City, Quezon. It was assumed that coconut oil was transported by fuel tank truck with 20,000 liter of load with emission factor of this heavy truck in Manila was 800gCO2eq./km [11].

The following solution outline shows how the kg $CO_2$ due to this coconut oil transport per kilometer travelled by PUJ was determined.




**Biodiesel Production and Purification:** The calculations for the GHG emissions during the coconut biodiesel production and coconut biodiesel purification were based on energy consumption data measured by Hewa Walpita et al. (2012) in a pilot scale biodiesel plant producing 27.5 liters biodiesel per batch [11].

**Table 3**. Energy Consumption in Biodiesel Production and Purification

| BIODIESEL PRODUCTION STAGE | EQUIPMENT | Electrical energy consumption in kWh/ batch |
|---|---|---|
| Methoxide reaction | Mixing motor | 0.002 |
| | Control system | 0.004 |
| Oil pre-heating | Electrical heaters | 0.7 |
| | Circulation pump | 0.043 |
| | Solenoid valves | 0.005 |
| | Control system | 0.006 |
| Reaction stage | Electrical heaters | 3 |
| | Circulation pump | 0.555 |
| | Solenoid valves | 0.06 |
| | Control system | 0.075 |
| Layer separation | Circulation pump | 0.031 |
| | Solenoid valves | 0.003 |
| | Control system | 0.004 |
| **BIODIESEL PURIFICATION STAGE** | **EQUIPMENT** | **Electrical energy consumption/ batch** |
| Biodiesel Washing | Oxygen pump | 0.03 |
| | Solenoid valves | 0.003 |
| Biodiesel drying | Electrical heaters | 2 |
| | Circulation pump | 0.123 |
| | Solenoid valves | 0.013 |
| | Control system | 0.017 |

This work assumes that this technology uses electrical energy to power the equipment in the biodiesel production and purification.

Aside from energy inputs, the material inputs also contribute $CO_2$ emissions during their manufacturing. The following data were used for the calculations:

- 6.6 mol methanol: 1 mol coconut oil
- MW of coconut oil: 660 g/mol
- 0.8457 kg coconut oil yields
- 1 kg CME and 0.111 kg glycerin

The summary of inputs and outputs is shown in Figure 7:

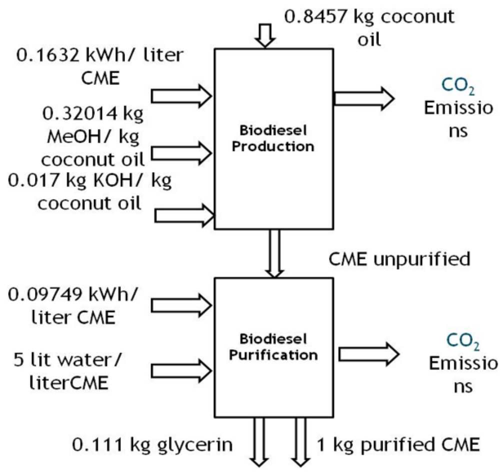
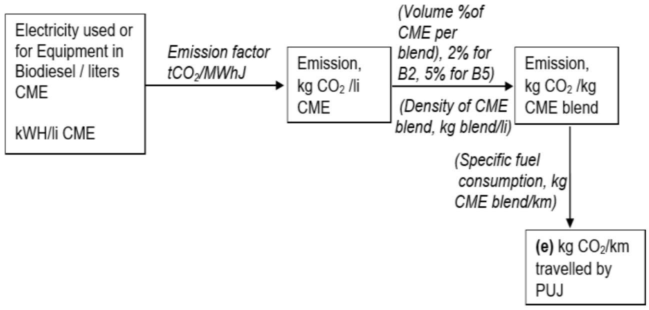


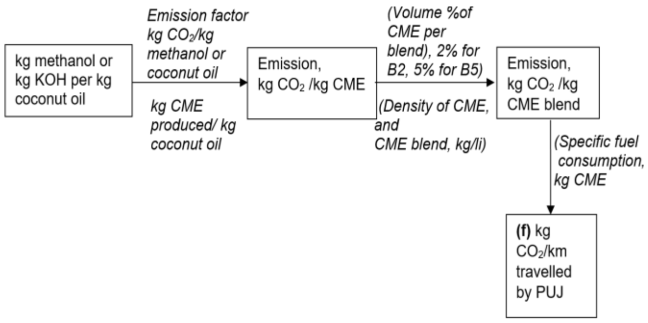

**Figure 7.** Summary of material and energy inputs, and outputs in Biodiesel Production and Purification

Methanol is assumed to be produced from natural gas and has an emission factor of 1.68 kg $CO_2$/kg methanol. Production of KOH has an emission factor of 1.94 $kgCO_2/kg$ KOH.

For $CO_2$ emissions from energy usage, the solution outline is:




For material inputs, the solution outline used is:




The kg $CO_2$ emissions from copra processing, coconut oil production, transport of coconut oil to CME plant, and biodiesel production and purification stages [(a), (b), (c), (d), (e), and (f)] were added. These emissions represent the emissions from material processing and manufacturing of the CME content in the biodiesel blends. This was then added to the $CO_2$ emissions from crude oil refining to produce the 98 and 95% by volume diesel content of the CME blends.

**Transport from CME Plant to Refueling Stations:** In calculating the $CO_2$ emissions for transport of the coconut biodiesel, the location of CME plants in Lucena City, Quezon was considered. The average distance from CME plant to refuel stations in Metro Manila is 314.8 km (roundtrip). It was assumed that biodiesel was transported by fuel tank truck with 20,000 liter of load with emission factor of this heavy truck in Manila was 800$gCO_2$eq./km [11].

Calculation outline used was the same as that in neat diesel transport to Metro Manila, applying the distance from Lucena City, Quezon.

The same as in other stages, the total $CO_2$ emissions were obtained from the transport of CME content and diesel content in the CME blends.

**Use in Public Utility Jeepneys:**

Studies on the tailpipe emissions of engines using Philippine CME blends only included measurement of regulated pollutants Total Hydrocarbon, Carbon Monoxide, and Nitrogen Oxides. Measurement of $CO_2$ emissions from the engines is not included.

Since there is no data available on actual measured amount of $CO_2$ emissions, the equation 1 was used.

For the biodiesel blends, the $CO_2$ emissions are equal to the emission from fossil fuel diesel and emission from the coconut methyl ester.

To determine the amount of fuel per kilometer, the calculations used data on specific fuel economy, SFC (g/km) of jeepney engines that used 2% and 5% by volume coconut biodiesel blends. The SFC was obtained from a study of the performance of the CME blends in engines of public utility jeepneys in Metro Manila.

**Table 4**. Specific Fuel Consumption of Jeepneys using coconut biodiesel blends B2 and B5 [20]

| Coconut Biodiesel Blend | Specific Fuel Consumption, g/km |
|---|---|
| B2 (2% CME, 98% diesel ) | 140.3 |
| B5 (5% CME, 95% diesel) | 133.8 |

The carbon content of coconut methyl ester was determined using the data on the fatty acid profile (%mass) of coconut methyl ester, which was determined by Bello, et al. (2015) using Gas Chromatography (GC)-Mass Spectrometry (MS) and GC-FID (Flame Ionization Detector) [21].

**Table 5**. Fatty Acid Profile (%Mass) of Coconut Methyl Ester [21]

| Fatty Acid | Molecular Formula | Number of Carbons | %Mass | Molecular Weight, kg/kmol |
|---|---|---|---|---|
| Caprylic Acid | $C_8H_{16}O_2$ | 8 | 8.86 | 144.21 |
| Capric Acid | $C_{10}H_{20}O_2$ | 10 | 6.17 | 172.26 |
| Lauric Acid | $C_{12}H_{24}O_2$ | 12 | 48.83 | 200.3178 |
| Myristic Acid | $C_{14}H_{28}O_2$ | 14 | 19.97 | 228.3709 |
| Palmitic Acid | $C_{16}H_{32}O_2$ | 16 | 7.84 | 256.4 |
| Stearic Acid | $C_{18}H_{32}O_2$ | 18 | 3.06 | 284.48 |
| Oleic Acid | $C_{18}H_{34}O_2$ | 18 | 4.44 | 282.47 |
| Linoleic Acid | $C_{18}H_{32}O_2$ | 18 | 0.76 | 280.4472 |
| Others | | | 0.07 | |

The assumed purity of coconut methyl ester is 96.5% to account for moisture, glycerin, and others. [21]

**Table 6**. The results of converted $CO_2$ emissions for the stages

| Fuel | Extraction ($kg\ CO_2 km$) | Production ($kg\ CO_2 km$) | Transport ($kg\ CO_2 km$) | Use phase ($kg\ CO_2 km$) |
|---|---|---|---|---|
| Neat Diesel | 0.036322239 | 0.070139748 | 0.001735607 | 0.4 |
| B2 | 0.040883213 | 0.080448487 | 0.001983242 | 0.381011 |
| B5 | 0.038105861 | 0.077666986 | 0.001891462 | 0.363273 |

The calculation results will be summarized and discussed in the next section.

### 3.2. Results and discussion

#### 3.2.1. Emission Factor of CME

The calculated emission factor using the fatty acid profile or composition is 2.5539 kg $CO_2$/ kg CME. This was calculated because there is no available data on actual or measured CME emission factors. Studies on performance of Philippine automotive vehicles using CME as fuel only measured the regulated pollutants Carbon monoxide, Total Hydrocarbons, $NO_x$ emissions and particulate matter.

#### 3.2.2. $CO_2$ emissions in life cycle of fuels

The result focuses on evaluating the total $CO_2$ emissions generated throughout the life cycle of neat diesel and biodiesel blends, specifically CME (Coconut Methyl Ester) blends B2 and B5. Life cycle analysis (LCA) encompasses emissions from production, transportation, and use phases, offering a comprehensive understanding of the environmental impacts.

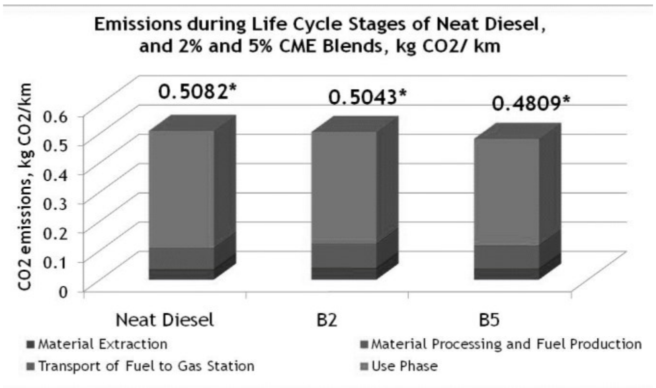



**Figure 8.** Total $CO_2$ emissions during life cycle of neat diesel, and CME blends B2 and B5

From the Figure 8, total $CO_2$ emissions from life cycles of B2 and B5 are lower by 0.767% and 5.37%, respectively, compared to that of emissions from life cycle of neat diesel. By comparing neat diesel with the lower biodiesel blends, this analysis highlights the potential of CME to reduce greenhouse gas emissions and contribute to sustainable fuel practices.

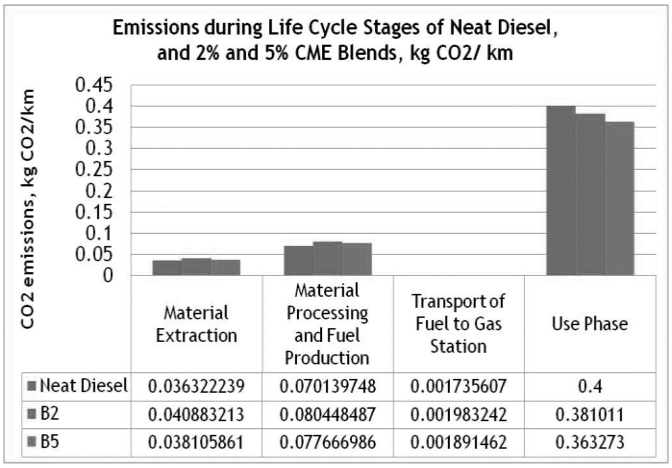



**Figure 9.** $CO_2$ emissions during life cycle of neat diesel, and CME blends B2 and B5

It is also seen from the study that the majority (75-78%) of $CO_2$ emissions associated with the life cycle of neat diesel and CME (coconut methyl ester) blends, such as B2 and B5, occur during the use phase, rather than during production, transportation, or other stages (in Figure 9). This highlights that the combustion of these fuels in engines is the dominant contributor to their overall carbon footprint. Consequently, efforts to reduce CO2 emissions from these fuels should prioritize improvements in engine efficiency or transitions to cleaner combustion technologies, as well as exploring blends with higher biofuel content or alternative energy sources.

#### 3.2.3. CME Raw Material Extraction to CME Production and Purification

This part provides a comprehensive overview of the carbon footprint of CME production, highlighting the contributions of each stage to the overall lifecycle emissions from coconut farming to the conversion of coconut oil into CME. Understanding these emissions is essential for identifying opportunities to improve sustainability and reduce the environmental impact of CME as a biodiesel alternative.

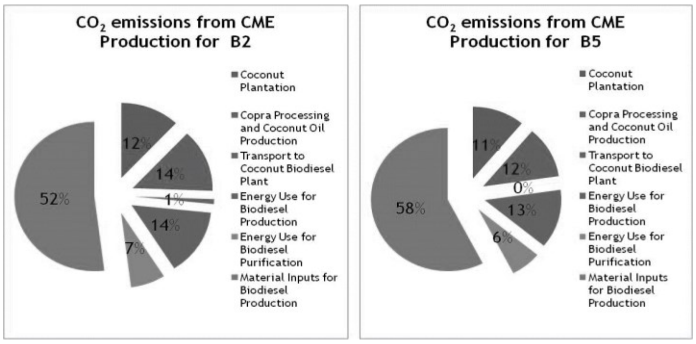



**Figure 10.** $CO_2$ emissions from coconut farming to production of CME

In Figure 10, considering the life cycle of Coconut Methyl Ester from Coconut Farming to CME Production, 52-58% of the $CO_2$ emissions come from the manufacturing of material inputs during Biodiesel Production. This includes Methanol and KOH catalyst for the trans-esterification process.

In the total $CO_2$ emissions from biodiesel purification and production (including from material and energy inputs), 65.94-70.14% of emissions come from production of methanol. The 6.6: 1 mole ratio of methanol to coconut oil in the CME production is one of the factors contributing to high $CO_2$ emissions from material inputs for biodiesel production. Another factor for the high $CO_2$ emissions from methanol as input is that it was assumed it to be produced from natural gas. The process of which has higher $CO_2$ emissions as compared to other sources of methanol. These findings highlight the importance of optimizing material inputs and exploring alternative methanol sources to reduce the carbon footprint of CME production.

**4. Conclusion**

1. Increasing the blend percentage of CME in the fuel decreases the $CO_2$ emissions from the raw material extraction to the use phase in PUJs. However only a minimal percentage of reduction is observed: 0.767% and 5.37%, for B2 and B5 respectively, compared to that of emissions from life cycle of neat diesel.

Extending the comparative life cycle assessment to blends with higher CME volume percentage (eg. B20) may show more significant reductions in total $CO_2$ emissions. This entails the measurement of specific fuel consumption for jeepneys using B20 blend.

2. Of the emissions during the life cycle of the fuels (neat diesel, B2, and B5), 75-78% of the emissions during the life cycle of the fuels (neat diesel, B2, and B5) come from the USE phase: as fuel for PUJs in Metro Manila. $CO_2$ tailpipe emissions are correlated with the specific fuel consumption. Therefore, factors -other than fuel type- such as engine efficiency of Public Utility Jeepneys should be increased to realize a significant reduction of $CO_2$ emissions.

3. Considering the life cycle of Coconut Methyl Ester from Coconut Farming to CME Production, 52-58% of the $CO_2$ emissions come from the manufacturing of material inputs during Biodiesel Production.

The reduction of required mole ratio of methanol to coconut oil in the CME production is a potential focus for future studies on optimization of trans-esterification process.

Sources of methanol, other than natural gas, with less net $CO_2$ emissions may also be considered. Another option that may also be considered is the use of other reactants such as ethanol for the trans-esterification process.

To increase the use of biofuels in transportation in the Philippines, a comprehensive approach involving policy, infrastructure, education, and market incentives is required. Here are some actionable recommendations:

- Gradually raise the mandated biodiesel blend from B2 (current) to B5 or higher (e.g., B10 or B20), aligning with international standards.

- Invest in more biodiesel and bioethanol production plants, particularly near agricultural hubs, to reduce transportation costs.

- Offer subsidies or reduced taxes for the production, sale, and use of biofuels.

- Launch nationwide campaigns highlighting the environmental and economic benefits of biofuels.

- Engage private companies to co-invest in biofuel infrastructure and production.

- Develop mechanisms to stabilize biofuel prices and make them competitive with fossil fuels.
- Ensure biofuel production adheres to sustainability criteria to prevent deforestation and loss of biodiversity, etc.

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