



Greenhouse Gas Reduction of an Advanced Philippine Coco-Biodiesel Refinery Strategic to the Philippine Nationally Determined Contribution



DOI: 10.47125/jesam/2025_sp1/04

ABSTRACT

To assess biodiesel's sustainability and its role in the country's GHG reduction efforts, a cradle-to-grave carbon footprint of a 90 million liter per year (MLPY) coconut biodiesel refinery in the Philippines (CBP) was assessed using primary data, verified through material and energy balance simulations. The company's 2019 inventory was used in the analysis to curtail the effects of COVID-19 pandemic in the actual annual production. Key assumptions and limitations included no land-use change, the application of carbon neutrality, the economic allocation method, and the IPCC 2013 assessment method within the SimaPro v.9.0.0.49 database. The estimated carbon footprint of the coco-biodiesel is 0.79891 kg CO₂e kg⁻¹ or 0.70863 kg CO₂e L⁻¹. CBP coco-biodiesel offers a GHG reduction of about 77.89% compared to fossil diesel (L L⁻¹ basis, cradle-to-grave), which satisfies the nationally determined unconditional GHG reduction contribution of the Philippines to the United Nations Framework Convention on Climate Change set at 2.71%. Between the blends B3 and B4, it is projected to reduce diesel transport GHG emissions by 2.34-3.11%. Sensitivity analyses examined the outcome of using energy allocation and assessed various local production variables, such as, coconut farming practices, varying nut yields, sources of crude coconut oil for RBD (refined, bleached, deodorized) refining, and the type of refining employed.

Keywords: carbon footprint, biodiesel, Philippines, life cycle, GHG reduction, coconut, flow representativeness, flow reliability

Bernadette T. Magadia^{1*}
Rex B. Demafelis¹
Anna Elaine D. Matanguihan¹
Butch G. Bataller¹
Rey Sta. Maria²
Dean Lao, Jr.²

¹ Department of Chemical Engineering,
College of Engineering and Agro-
Industrial Technology, University of
the Philippines Los Baños, College,
Laguna, Philippines 4031

² Chemrez Technologies, Inc.,
Philippines

*corresponding author:
btmagadia@up.edu.ph

INTRODUCTION

In response to sustainability and climate change mitigation efforts worldwide, coupled with the volatile prices of petroleum fuels, the Philippine government enacted the Republic Act No. 9367, also known as the "Biofuels Act of 2006." The primary aim of the Act is to reduce the country's dependence on imported fuels, while considering public health, the environment, and the expansion of livelihood opportunities. A mandated blending was enforced, which created the market and emergence of local biofuel companies in the country—13 bioethanol and 13 biodiesel refineries (Board of Investments 2011).

In 2018, the global transport emissions accounted for 21% of the total emissions, where about 75% came from road vehicles (Ritchie 2020). In the Philippines, 25% was contributed by this sector in 2018 and 2019 (ClimateWatch 2022). To decarbonize transport, a transition to efficient and affordable innovative technology is vital. Combustion engines will remain the most important factor in this process, hence, the need to develop biofuels (Unglert et al. 2020). In the 2017 report by the Asian Development

Bank on Pathways to Low-Carbon Development for the Philippines, improvement of policies enhancing the use of cleaner alternatives to fossil fuels remains as a main strategy (Asian Development Bank 2017).

Bioenergy has the climate change mitigation potential when it can deliver lower environmental impacts than its fossil fuel counterpart (Brandão et al. 2018). Studies have proven biofuels to be cleaner than fossil fuels in terms of GHG emissions (Demafelis et al. 2020; Pereira et al. 2019; Obligado et al. 2017; Cavalett et al. 2013; Wang et al. 2012). The United States transportation emissions accounted for 28% of the 6.667e⁺⁹ Mg CO₂e emitted in 2018 (Liu et al. 2021). With its biofuels production and displacement of fossil fuels from 2006 to 2015, it has accumulated carbon emissions reduction amounting to 589.3e⁺⁶ Mg, comparable to removing 124 million cars from the road over this period (Biotechnology Industry Organization 2015). In Europe, the Renewable Energy Directive for the transportation sector supported biofuels that have at least 35% of greenhouse gas emissions reduction, and was recently revised to 65% from 2021

onwards (*Brandão et al. 2021*).

The biofuels law is considered one of the driving forces to reduce the transportation sector's greenhouse gas (GHG) emissions and to attain the Philippines' commitment to the Paris Agreement. The Agreement targets to limit the rise in global temperature to a maximum of 2°C by 2050, equivalent to a carbon budget of 750e⁺⁹ Mg CO₂e until then (*Unglert et al. 2020*). In 2018, the total global emission was at 60⁺⁹ Mg CO₂e annually (*UNEP 2018*), hence it is imperative for a global action to reduce emissions. Under the country's Nationally Determined Contribution (NDC) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) last 15th of April 2021, the Philippines intends to reduce its GHG emissions by 75% (wherein 2.71% is unconditional and 72.29% is conditional) in 2030 relative to its business-as-usual scenario between 2020 and 2030.

In the Philippines, domestic biodiesel production is solely sourced from coconut. Coconut is the third most dominant crop in the country (*Dar 2019*), and covers about one-fourth of the total land area devoted to agriculture (*Javier 2015*). Compared to other biodiesel crops, coconut is the most suited to the archipelagic geography of the country as it is typhoon-resilient and adaptive to saline conditions (*Javier 2015*). The coconut industry produces 15 primary products, including fresh coconut, copra, coconut oil, copra cake, desiccated coconut, coconut shell, shell charcoal, shell flour, coconut husk, mattress coir fiber, coir bristle, coir dust and shots, whole nuts, husked coconuts, and coconut water. Approximately 75% of these products are exported, illustrating the industry's significance to the national economy (*Moreno et al. 2020*). However, coconut production remains largely uncompetitive, with an unstable and underdeveloped market that discourages farmers from further venture into the crop. Consequently, many coconut farmers face economic hardship and remain among the poorest within the supply chain (*Moreno et al. 2020*). The Biofuels Act of 2006 provides an additional market for coconut farmers through increased demand for coconut-based biodiesel. To meet a proposed 1% increase in biodiesel blending with coconut methyl ester (CME), projections indicate the need for around 900 million additional coconuts to produce the necessary 100-120 million liters of CME (*DOE 2024a*).

As of October 2024, the mandated biodiesel blend by volume with respect to all diesel fuel sold by all oil companies in the country stands at 3%, with the approved resolution to incrementally raise it by 1% each year until it reaches 5% in 2026 according to the Department

Circular No. DC 2024-05-0014 (*DOE 2024b*). A study by the Asian Institute for Petroleum Studies Inc. (AIPSI) stated that if this increased to 5%, about 430 million liters per year of diesel imports would be avoided. This would, in turn, introduce environmental and social benefits. The Philippine Coconut Authority has estimated the total economic benefit of shifting to 5% biodiesel blend amounting to PhP 110 Billion per year (USD:PhP rate in 2019 was 1: 51.7675) (*Dar 2019*).

The environmental performance of bioenergy systems such as biodiesel varies widely due to several factors, such as the crop type used, the land-use system, the variability in agroclimatic conditions, and the conversion technology (*Brandão et al. 2018*). Biodiesel refineries in the Philippines differ in production strategies, technologies, efficiencies, and even input sourcing and market deliveries, hence, could be expected to vary in their environmental performances and other refineries could not directly adopt one's GHG performance. In this specific study, an actual biodiesel refinery in the Philippines with a Department of Energy (DOE)-rated capacity of 90 million liters per year (MLPY) was assessed for its carbon footprint and equivalent GHG reduction potential relative to fossil-derived diesel. Most common in life cycle assessments for biodiesel production in existing literature rely on secondary data for process inputs and outputs (*Yani et al. 2022; Demafelis et al. 2020; Varanda et al. 2011; NREL 1998*). As noted by the *National Renewable Energy Laboratory (1998)*, many inventory flow estimates are highly uncertain due to factors, such as limited data, poorly characterized processes, and proprietary information. This often leads to Life Cycle Assessments (LCAs) relying on national, regional, or industry averages, as most firm-specific data is proprietary. Similarly, *Srikumar et al. (2024)* highlighted that the lack of reliable, accurate, and up-to-date data, particularly regarding specific area conditions and feedstock production methods, presents a major challenge in biodiesel production LCAs. Access to trustworthy life cycle inventory data is essential for conducting thorough analyses.

This study conducts an LCA of biodiesel production using firsthand company data, ensuring high reliability and representativeness in material, energy, and emission flows. Following the U.S. Environmental Protection Agency's (US EPA) data quality matrix, the data reflects a full year of operations with high temporal, geographical, and technological accuracy. Material and energy balance calculations were used to validate data accuracy, supporting an estimated process completeness of >80%.

MATERIALS AND METHODS

Data Types and Sources

Primary data were collected directly from a coco-biodiesel plant (CBP) in the Philippines, which has a production capacity of 90 million liters per year (MLPY). The plant provided comprehensive production data, including information on raw material sources and customer destinations for the final product. The biodiesel is manufactured from refined, bleached, and deodorized coconut oil (RBD CNO) sourced from another Philippine-based supplier. The carbon footprint of the produced coco-biodiesel was assessed using an attributional LCA model.

The obtained data were validated by conducting material and energy balances using a commercial process simulation software. The results of the verification were deliberated by the team composed of LCA experts and process engineers, capable of interpreting deviations from the computations to ensure that the company maintained accurate inventory accounting. The inventory data reflected the company’s production activities throughout 2019. For the upstream coconut production processes in the country, secondary data from another study were utilized (Demafelis et al. 2019), which is also based on primary data collection by the same proponents of this study.

This life cycle assessment started from the plantation up to the end-use of the biodiesel produced (cradle-to-grave), applying economic allocation when there were co-products along the production chain. The ISO 14040:2006 LCA Framework was followed in this study.

Life Cycle Assessment Method

Goal and Scope Definition. In this study, SimaPro 9.0.0.49 (PRé Sustainability 2019) was used in the conduct

of the life cycle assessment of CBP’s coco-biodiesel. All data inputs in SimaPro were obtained from the material and energy balances based on the actual 2019 production data of CBP (Table 1).

System Boundary. The LCA included coconut cultivation, harvesting and copra making in the field/plantation, crude coconut oil (CNO) production at the oil mill, CNO refining, biodiesel production at CBP, and biodiesel end-use. Also included in the system boundary are hauling and transport of the raw materials that are vital in the supply chain (Figure 1).

Life Cycle Inventory

Coconut Cultivation and Harvesting. Since the period covered in the assessment is only for the year 2019, carbon footprints during land preparation and planting of coconut were not covered, as most of the coconut plantations in the country have been established for more than twenty years. Land-use change was not considered as well because these coconut plantations were not newly established. Nevertheless, the cultivation and harvesting of coconut for one year were accounted for in carbon inventory.

Based on the study of Demafelis et al. (2019), most coconut farmers all over the country do not apply soil amendments or additives, soil tillage, and pest and disease management. Typical coconut farms in the country only apply about 2 kg of sodium chloride (NaCl) or salt annually for every tree, especially only when the Philippine Coconut Authority (PCA) supplies them (Table 2).

Only the use of salt (NaCl) was accounted for in the carbon inventory during this stage. The labor and the use of carabao for hauling were not included in the LCA. Interviews with Philippine Coconut Authority (PCA) and Salinas Salt Farm revealed that NaCl is commonly

Table 1. Goal and scope definition for the life cycle assessment of a commercial coco-biodiesel plant in the Philippines.

Components	Particulars
Goal	Conduct life cycle assessment in determining the carbon footprint and GHG reduction potential of CBP biodiesel, identify environmental hotspots of the system, investigate other upstream supply chain scenarios, and compare its carbon footprints to biodiesel from other countries, using CBP’s actual production data in 2019, and to ultimately recommend strategy/ies in reducing further its carbon footprint.
System Boundary	Coconut cultivation and harvesting to biodiesel end-use “Cradle-to-grave”
Functional Unit	kg CO ₂ e L ⁻¹ biodiesel, kg CO ₂ e kg ⁻¹ biodiesel
Impact Method	IPCC2013 GWP100a
Allocation Method	Economic Allocation
Assumptions and Limitations	Base case upstream production data and practices are obtained from Demafelis et al. (2019) while other inputs attributed to CBP biodiesel production are obtained from the SimaPro (Ecoinvent 2019 and Blonk Sustainability 2019) database. Infrastructure-related emissions are not part of the system boundary of the study. Carbon neutrality concept was applied in carbon footprint accounting.

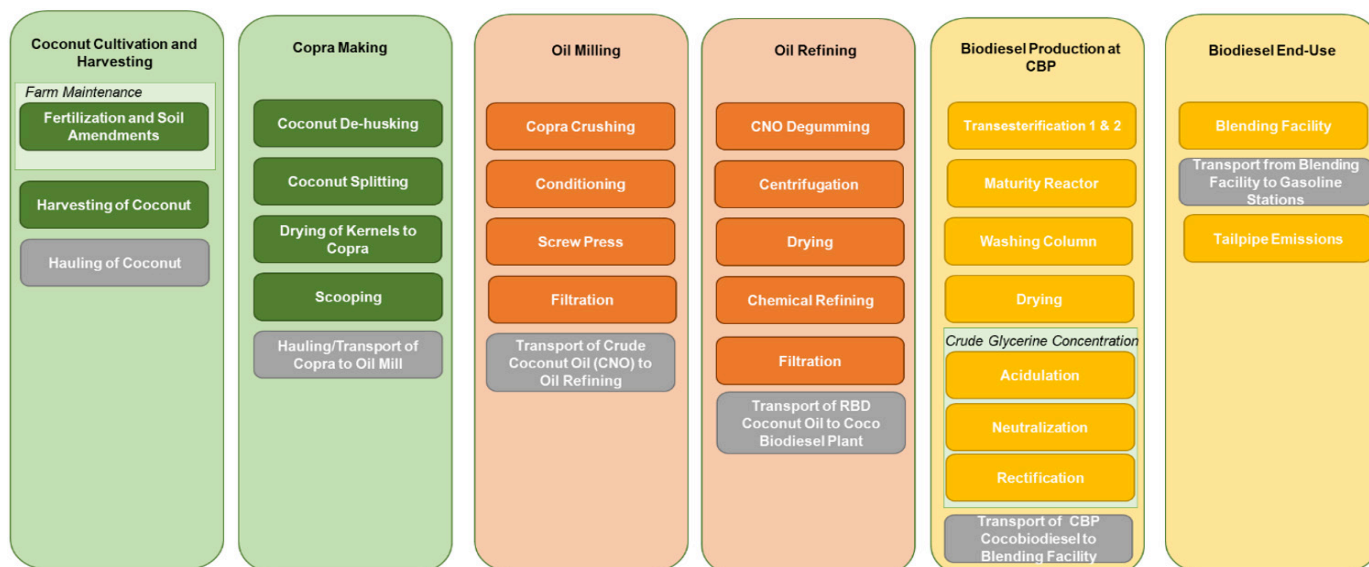


Figure 1. System boundary considered in the life cycle assessment of a commercial Philippine coco-biodiesel refinery from cradle-to-grave; Note: The gray color indicates transportation occurring outside of the process stage itself; the colors represent different phases: green for the farming side, orange for coconut oil refining, and yellow for biodiesel production and end-use.

Table 2. Data used in coconut cultivation and harvesting for the commercial Philippine coco-biodiesel refinery carbon inventory.

Practices/ Parameters	Values
No. of trees/ha	100
Nut Yield (nut/tree)	70
Nut Weight (kg/nut)	0.955
Fertilizers and usage, NaCl (kg/tree)	2
Mode of fertilization and harvesting	Manual
Mode of Hauling	Carabao

Source: Demafelis et al. (2019)

sourced in Pangasinan, wherein salt is processed from seawater manually.

The study employed the carbon neutrality concept, wherein the carbon balance (e.g., carbon sequestration respiration, etc.) within the coconut farm ecosystem was not accounted for in this assessment.

Copra Making. Copra, the source of coconut oil, is produced by drying the kernel part of the fruit. Typically, the first steps in copra making are dehusking and splitting of mature coconut fruit manually at the field, thereby separating the husk and coco-water from the kernel and shell. The kernel, together with the shell, is dried in a “tapahan” until its moisture content decreases to about 6%. Using the coconut shell and husk as fuel in copra drying is a common practice in most farms in the country. Copra is then scooped out manually out of the shell and sold to oil mills to extract and/or refine the oil. Values used for carbon inventory in copra drying are summarized below (Table 3).

Emission factors of GHGs, except CO₂, in combusting coconut shell and husk as fuel during copra drying were obtained from default US EPA 2014 emission factors during stationary combustion of wood or wood residuals

Table 3. Data used in copra making for the carbon inventory of a commercial Philippine coco-biodiesel refinery.

Item	Value
Copra yield (kg copra kg ⁻¹ kernel)	0.25 ¹
Coconut shell and husk requirement for copra drying (g coco shell and husk kg ⁻¹ dried copra)	842.11 ²
Copra to Oil Mill Transport Distance (km)	80 ¹
Truck Transport Data	Transport, truck 10-20t, EURO4, 100%LF, default/GLO Energy ³
Coconut Shell and Husk Emission Factors	
Methane (g CH ₄ MJ ⁻¹)	7.2 ⁴
Nitrous Oxide (g N ₂ O MJ ⁻¹)	3.6 ⁴

¹Demafelis et al. (2019)

²Swain et al. (2014)

³SimaPro Database (Ecoinvent 2019 and Blonk Sustainability 2019)

⁴USEPA 2014

having comparable calorific value with coconut husk and shell. These data are not available in the SimaPro database. Note that CO₂ emissions during the stationary combustion of shell and husk for copra drying were not accounted for because of the carbon neutrality concept explained in the assumptions and limitations section, wherein the CO₂ released during the combustion was primarily the carbon sequestered in the biomass.

Economic Allocation (Copra). The economic allocation factor applied for copra is 0.7501. This factor indicates that 0.7501, or 75.01%, of the total calculated carbon footprint for the entire coconut production is assigned to the production of copra. The factor is calculated by multiplying the quantity of each component, Q_i , by its corresponding economic value, Ev_i , and then proportionally allocating their total to determine the allocation factor (Equation 1).

$$\text{Allocation Factor}_i = \frac{Q_i Ev_i}{\sum_i^n Q_n Ev_n} \quad (1)$$

Copra Hauling. The transportation data were expressed in SimaPro in terms of ton-km, derived by multiplying the amount of copra to be delivered and the transport distance (Equation 2).

$$\begin{aligned} \text{Transport data for entry in SimaPro (T - km)} = \\ \text{Amount of copra (T)} * \\ \text{Transportation Distance (km)} \end{aligned} \quad (2)$$

Oil Milling. Prior to crude coconut oil (CNO) extraction via screw pressing, copra is prepared by crushing, wherein the copra size is reduced, and then by conditioning, wherein the crushed copra is heated to about 104-110°C for better extraction and further moisture reduction (Table 4).

Potential CO₂ emissions from waste streams (foots) are again part of the carbon neutrality concept, therefore, were not accounted for in the carbon inventory.

Economic Allocation (CNO). After oil extraction, crude CNO is separated from copra meal (solid residues after extraction) via filtration. The copra meal has an economic value and is usually sold to the feed industry, making it a co-product of oil milling. Economic allocation was again performed to determine the carbon footprint attributed only to crude CNO, as this is the product of interest for biodiesel production. The allocation factor for crude CNO calculated based on crude CNO requirement of CBP in 2019 and the crude CNO and copra meal prices in 2019 is 0.8580 and leaves 0.1420 for copra meal. The values were obtained based on the annual raw material requirement of the company in 2019 and the prices of crude CNO at PhP 36.64 kg⁻¹ and copra meal at PhP 10.67 kg⁻¹ by the Philippine Coconut Authority in June 2019.

CNO Hauling. CNO hauling data used were from the actual sources of RBD CNO Company. The approximate calculation which considered the land and sea transport route of the CNO from the source up to the RBD refinery amounted to 7,167,155.79 Mg-km for land and 26,820,185.92 Mg-km for sea transport.

Data used to model the transportation from the SimaPro database for land and sea transportation is Transport, truck 10-20t, EURO4, 100%LF, default/GLO Energy, and Transport, sea ship, 80000 DWT, 100%LF, middle, default/GLO Energy, respectively.

Oil Refining. Oil refining primarily involves two major operations- degumming and refining. Oil degumming aims to remove the phospholipid content of the oil using either phosphoric acid or citric acid forming “gums.” The gums are separated from CNO via centrifugation.

Oil refining involves the reduction of free fatty acid content of the oil by physical or chemical refining. In physical refining, the moisture content of the oil is first reduced through drying and then free fatty acid is stripped using steam in a packed column deodorizer. The

Table 4. Data used in oil milling for the carbon inventory of a commercial Philippine coco-biodiesel refinery.

Item	Value
CNO Yield (kg CNO kg ⁻¹ copra)	0.63 ¹
Copra Crushing and Pressing Power Requirement (hp kg ⁻¹ copra)	0.06 ²
Copra Pressing Power Requirement (hp kg ⁻¹ copra)	0.06 ³
Coconut shell and husk use during conditioning (g coco shell and husk (kg ⁻¹ conditioned copra)	15.23 ¹
Coconut Shell and Husk Emission Factors	
Methane (g CH ₄ MJ ⁻¹)	7.2 ⁴
Nitrous Oxide (g N ₂ O MJ ⁻¹)	3.6 ⁴

¹Demafelis et al. (2019)

²www.nzdl.org

³Assumed similar power requirement as copra crushing

⁴USEPA 2014

equipment operates at vacuum pressure and a temperature of 250°C. Steam flows counter-currently with the oil and carries the free fatty acid at the top of the column. Coconut Fatty Acid Distillate (CFAD) will be condensed by direct contact using cooled CFAD. Filtration is the last step in oil refining, wherein the waste stream, composed of mostly soap, sodium hydroxide, and water is removed from the oil component, producing a refined CNO.

The materials for the carbon footprint accounting of the oil refining stage included phosphoric acid, bleaching earth, activated carbon, coal and diesel usage for the steam requirement, electricity requirement and the transportation of RBD to the CBP facility. The data were provided by CBP as communicated by their supplier. The RBD oil yield per kg CNO is 94%.

Economic Allocation (RBD). Coconut Fatty Acid Distillate (CFAD) is a by-product of the physical oil-refining process with economic value. Hence, economic allocation was done to determine the carbon allocation factor for RBD oil, which was computed to be 0.9654, and 0.0346 for CFAD, based on material annual raw material requirement of the company in 2019.

RBD Hauling. The freight transport of RBD to the Company is about 952,346.30 Mg-km. The inventory used the truck >20t, EURO4, 100%LF, empty return/ GLO Energy database in SimaPro. Carbon dioxide emissions from wastewater produced in oil refining is not accounted for as it is part of the carbon neutrality concept.

Biodiesel Production. From the data provided by CBP, a series of process discussions, validation meetings, and plant visits were conducted to confidently come up with the company's balanced coco-biodiesel process data inputs and outputs for the 2019 operation. The values obtained from these activities were verified through simulation of the plant using the local RBD property by Dayrit *et al.* (2007).

The inventory consisted of the energy use from diesel used during operations including the diesel consumption of forklifts and dump trucks inside the facility, gasoline consumption of vehicles, coal, and electricity consumption both for the administrative buildings and processing facilities; chemical inputs including the RBD CNO, hydrochloric acid, sodium hydroxide, catalyst, and alcohol; fugitive emissions from the refrigerant, wastes and wastewater recycling; and the products and co-products of the process including the biodiesel, glycerol, and acid oil.

Philippine Coco-biodiesel Carbon Footprint and NDC

The emission data for the material and energy inventory are based on the global {GLO} average production in the SimaPro database. Actual transportation data provided by the company from the point of origin of these materials and energy inputs to the company were accounted for.

Economic Allocation. CBP coco-biodiesel production had other co-products (Table 5). Based on economic allocation, coco-biodiesel had a carbon allocation factor of 0.9393.

Biodiesel End-Use. Finally, biodiesel is delivered to its market, typically oil depot or diesel-biodiesel blending facilities, as well as the transport of biodiesel-blended fuel to gasoline stations. The distance to the depots and final markets were recorded.

The CO₂ tailpipe emissions during combustion of the coco-biodiesel were not accounted for due to the carbon neutral system assumption- carbon sequestered from the biomass as raw material was just emitted via combustion of biodiesel for transport. However, the methane (1.1 g CH₄ mmBTU⁻¹) and nitrous oxide (0.11 g N₂O mmBTU⁻¹) emissions in tailpipe during biodiesel end-use are accounted for (EPA 2014).

Impact Assessment

The carbon footprint of the company's coco-biodiesel in terms of kg CO₂e L⁻¹ biodiesel within the defined system boundary was determined and assessed using the IPCC 2013 GWP100a V1.03 impact method. Base case data and practices were outlined in the System Boundary. In addition, the GHG emission reduction potential of CBP coco-biodiesel relative to a fossil fuel reference, expressed in percentage (%), was estimated (Equation 3). This equation aligns with the emission reduction formula, where project emissions are subtracted from baseline emissions (Asian Development Bank 2017).

$$GHG\ Reduction\ (\%) = \frac{Emissions_{fossil} - Emissions_{alternative}}{Emissions_{fossil}} \times 100 \quad (3)$$

Table 5. The economic allocation factor used for the coco-biodiesel from the refinery.

CBP Products	Allocation Factor ¹
Coco-biodiesel	0.9393
Glycerol (Domestic)	0.0186
Glycerol (For Export)	0.0333
Acid Oil	0.0086
CME Residue	0.0002

¹Based on material annual raw material requirement of the company in 2019

To gauge the environmental performance of the company, the estimated carbon footprints and GHG reduction potential of the company's coco-biodiesel relative to that from other countries were compared, qualifying the methodology and assumptions used for the values reported (**Table 6**).

Interpretation

The interpretation of the life cycle assessment involved the identification of carbon hotspots, conduct of sensitivity analyses, and the evaluation of results against the Philippines' Nationally Determined Contribution (NDC) commitment under the Paris Agreement.

Base case hotspot analysis was done to determine the components, technologies, and/or practices in the supply chain that significantly contribute to the total carbon footprint of the company's coco-biodiesel. In addition to using economic allocation for estimating carbon footprint attributed to the biodiesel production until its end-use, energy allocation was also observed. Sensitivity analyses in the upstream processes and during coco-biodiesel production such as varying nut yields and coconut farming practices were also conducted. Common CNO sources were considered for the RBD refinery as well as the type of refining (**Table 7**).

RESULTS AND DISCUSSION

Carbon Footprint and GHG Emissions Reduction Potential of Coco-Biodiesel

The total carbon footprint of biodiesel calculated was 0.7988 kg CO₂e L⁻¹ biodiesel (**Table 8**). Carbon footprint equivalents in terms of per kg CO₂e kg⁻¹ and g CO₂e MJ⁻¹ were also presented.

Using the default carbon footprint of fossil fuel used for transportation of 83.8 g CO₂e MJ⁻¹ (*International Sustainability and Carbon Certification 2010*), GHG reduction potentials of coco-biodiesel relative to fossil-derived diesel were 78.81%, 77.89%, and 76.26% for per kilogram fuel basis, per liter fuel basis, and per megajoule fuel basis, respectively. This result is promising, as it meets the sustainability criteria set by the EU Renewable Energy Directive (RED), which requires biofuels to achieve at least a 65% reduction in GHG emissions compared to fossil fuel alternatives (*Jeswani et al. 2020*). It aligns with studies showing that biodiesel can reduce GHG emissions by more than 75% compared to fossil fuels (*Xu et al. 2022; Tan et al. 2004*).

Table 6. Cradle-to-Gate CBP coco-biodiesel carbon footprint in comparison to biodiesel produced from other countries.

Methyl Ester	kg CO ₂ e kg ⁻¹ biodiesel				
	CBP Biodiesel	Soybean ME (Brazil)	Palm ME (Indonesia)	Soybean ME (USA)	Tallow ME (USA)
Carbon Footprint	0.7805	0.98	2.893	0.537	0.6970
GHG reduction potential (computed in reference to 3.77 kg CO ₂ e kg ⁻¹ diesel)	79.30%	74.01%	23.26%	85.76%	81.51%
System Boundary	Cradle-to-gate (until gate of facility)	Cradle-to-gate (until blending facility)	Cradle-to-gate (until gate of facility)	Cradle-to-gate (until gate of facility)	Cradle-to-gate (until gate of facility)
Assumption	No land-use change, applied carbon neutrality concept	No land-use change, applied carbon neutrality concept	No land-use change, applied carbon neutrality concept	No land-use change, applied carbon neutrality concept	No land-use change, applied carbon neutrality concept
Allocation Method	Economic, 93.93% to biodiesel	Mass, 90% to biodiesel	Normative allocation rules	Not specified	Not specified
Global Warming Potential	1 CO ₂ 28 CH ₄ 265 N ₂ O (IPCC 2013)	1 CO ₂ 25 CH ₄ 298 N ₂ O	1 CO ₂ 34 CH ₄ 298 N ₂ O	Not specified	Not specified
Source	This study	Cerri et al. (2017)	Wahyono et al. (2020)	Argonne National Laboratory (2021)	Argonne National Laboratory (2021)

Table 6. CBP coco-biodiesel carbon footprint in comparison to biodiesel produced from other countries. (cont.)

Methyl Ester	kg CO ₂ e kg ⁻¹ biodiesel					
	CBP Biodiesel	Rapeseed ME (steam from natural gas boiler)	Sunflower ME (steam from natural gas boiler)	Soybean ME (steam from natural gas boiler)	Palm ME	Waste Vegetable Oil or Animal Oil (UCO) ME
Carbon Footprint	0.7805	2.0275	1.5791	2.236	2.5985	0.8035
GHG reduction potential (computed in reference to 3.77 kg CO ₂ e kg ⁻¹ diesel)	79.30%	46.22%	58.11%	40.69%	30.07%	78.69%
System Boundary	Cradle-to-gate (until gate of facility)	Cradle-to-gate (until gate of facility)	Cradle-to-gate (until gate of facility)	Cradle-to-gate (until gate of facility)	Cradle-to-gate (until gate of facility)	Cradle-to-gate (until gate of facility)
Assumption	No land-use change, applied carbon neutrality concept	No land-use change, unknown if they applied the carbon neutrality concept	No land-use change, unknown if they applied the carbon neutrality concept	No land-use change, unknown if they applied the carbon neutrality concept	No land-use change, unknown if they applied the carbon neutrality concept	No land-use change, unknown if they applied the carbon neutrality concept
Allocation Method	Economic, 93.93% to biodiesel	Energy, 95.7% to biodiesel	Energy, 95.7% to biodiesel	Energy, 95.7% to biodiesel	Energy, 95.7% to biodiesel	Energy, 94.5% to biodiesel
Global Warming Potential	1 CO ₂ 28 CH ₄ 265 N ₂ O (IPCC 2013)	1 CO ₂ 23 CH ₄ 296 N ₂ O	1 CO ₂ 23 CH ₄ 296 N ₂ O	1 CO ₂ 23 CH ₄ 296 N ₂ O	1 CO ₂ 23 CH ₄ 296 N ₂ O	1 CO ₂ 23 CH ₄ 296 N ₂ O
Source	Source: This study	<i>Intelligent Energy Europe 2015</i>	<i>Intelligent Energy Europe 2015</i>	<i>Intelligent Energy Europe 2015</i>	<i>Intelligent Energy Europe 2015</i>	<i>Intelligent Energy Europe 2015</i>

Table 7. Alternative scenarios considered for the sensitivity analysis of the coco-biodiesel production from farm to facility.

Alternative Cases	Values for Sensitivity
A. Lower Nut Yield	50 nut per tree per annum
B. Higher Nut Yield but practicing recommended fertilizer requirement	90 nut per tree per annum using 1.5 kg ammonium sulfate per tree and 2.0 kg KCl per tree
C. CNO 100% sourced from Lucena	148 km distance via land transport
D. CNO 100% sourced from Bicol	431 km distance via land transport
E. CNO 100% sourced from Leyte	44.9 km distance via land transport and 861 km distance via sea transport
F. CNO 100% sourced from Zamboanga	24.9 km distance via land transport and 1,395 km distance via sea transport
G. CNO 100% sourced from Davao	54.9 km distance via land transport and 1,460 km distance via sea transport
H. RBD Refining	Chemical Refining Instead of Physical Refining for RBD production

Table 8. Carbon footprints and GHG reductions of the coco-biodiesel compared to fossil-derived fuel using different functional units (cradle-to-grave).

Unit	Carbon Footprint		GHG Reduction
	CBP Biodiesel	Diesel	
kg CO ₂ e kg ⁻¹ fuel	0.7989	3.77	78.81
kg CO ₂ e L ⁻¹ fuel	0.7086	3.20	77.89
g CO ₂ e MJ ⁻¹ fuel	19.8921	83.80	76.26

¹density of biodiesel used in the calculation is 0.887 kg L⁻¹ (Engineering Toolbox 2008)²HHV of biodiesel used in the calculation is 35.621 MJ L⁻¹ (Engineering Toolbox 2008)³density of diesel used in the calculation is 0.85 kg L⁻¹ (Engineering Toolbox 2008)⁴HHV of diesel used in the calculation is 38.243 MJ L⁻¹ (Engineering Toolbox 2008)

GHG Reduction with Respect to Philippines' Life Cycle Assessment Nationally Determined Contribution

These figures can be used to compute the contribution of incorporating biodiesel into the energy mix on the country's nationally determined contribution that aims to reduce emissions by 2.71%. If this target is to be met to be across all sectors and players, using data on diesel consumption in the Philippines and assuming an equal volume replacement with biodiesel, the following greenhouse gas (GHG) reduction potentials can be anticipated at various blending rates using the diesel pool on road use demand of the Philippines in YTD 2023f (*Mojica-Sevilla 2023*) (**Table 9**).

The result updates the projection by *Tan et al. (2004)* who have estimated a GHG reduction of 2.85-3.85% at B8 (8% coco-biodiesel and 92% diesel), which translates to 1.78-2.41% at B5; and the previous study by UPLB, which reported a 12.6-12.9% reduction at B20 (*Mojica-Sevilla 2022*), effectively 3.15-3.23% at B5.

The life cycle assessment of CBP's coco-biodiesel production, from cradle-to-grave, quantified the carbon footprint at each stage and standardized it to its contribution per liter of biodiesel produced. The carbon intensity begins at 0.0153 kgCO₂e per liter of biodiesel (equivalent to 0.0172 kgCO₂e per kg of biodiesel) for raw coconut. When processed into copra, the carbon footprint increases to 0.0546 kgCO₂e per liter. Extracting and producing crude coconut oil (CNO) raises it further to 0.0811 kgCO₂e per liter. Refining CNO results in a carbon footprint of 0.3399 kgCO₂e per liter of biodiesel. Producing biodiesel up to the gate of the factory has a carbon footprint of 0.6923 kgCO₂e per liter (or 0.7805 kgCO₂e per kg of biodiesel). Finally, including transportation and combustion, the total carbon footprint of the entire production process amounts to 0.7086 kgCO₂e per liter of biodiesel (0.7989 kgCO₂e kg⁻¹) (**Table 10**).

Table 9. CBP biodiesel's projected contribution to achieving the Philippines' nationally determined contribution (NDC) under the UNFCCC Paris Agreement.

Blending Mandate	Fuel Consumption (Million Liters)*		Emission Factor (kgCO ₂ e L ⁻¹)		GHG Emission (Million kgCO ₂ e)	GHG Emission Reduction (%)
	Diesel	Biodiesel	Diesel	Biodiesel		
0%	8,639.00	0	3.2	0.7086	27,644.80	Baseline
3%	8,379.83	259.17	3.2	0.7086	26,999.10	2.34%
4%	8,293.44	345.56	3.2	0.7086	26,783.87	3.11%
5%	8,207.05	431.95	3.2	0.7086	26,568.64	3.89%

*Total volume was based on the diesel demand in the Philippines in YTD 2023f (*Mojica-Sevilla 2023*)

Table 10. Carbon footprints and GHG reductions of coco-biodiesel compared to fossil-derived fuel using different functional units.

Product	Carbon footprint	
	kg CO ₂ e kg ⁻¹ biodiesel	kg CO ₂ e L ⁻¹ biodiesel
Coconut	0.0172	0.0153
Processing (Coconut shell & Husk Combustion)	0.0444	0.0394
Copra	0.0616	0.0546
Transport (to Milling)	0.0265	0.0235
Processing (Milling)	0.0034	0.0030
Crude CNO	0.0914	0.0811
Transport (to Refinery)	0.0260	0.0231
Processing (Refining)	0.2657	0.2357
RBD CNO	0.3832	0.3399
Transport (to Biodiesel Refinery)	0.0018	0.0016
Processing (Biodiesel Production)	0.3955	0.3508
Biodiesel (up to CBP gate)	0.7805	0.6923
Transportation	0.0158	0.0140
End-Use	0.0026	0.0023
Biodiesel (up to end-use)	0.7989	0.7086

component to the total carbon footprint of producing and using 1 kg of biodiesel were depicted from the thickness of the red lines per component or the level of the red bar inside every box or component, which highlighted the hotspots of the production. Note, however, that not all the components are shown. A cut-off of 2.8% was set, which means that those components with contribution of less than 2.8% were not shown in the network but accounted for in the overall carbon footprint.

The environmental performance of CBP's coco-biodiesel is compared with other production systems of other countries, utilizing their respective feedstocks. The basis of comparisons the value of the carbon footprint of coco-biodiesel up to CBP's gate (i.e., excluding the distribution and end-use emissions), which was 0.7805 kg CO₂e kg⁻¹ biodiesel (**Table 6**), to minimize variations in the distribution scenarios. In comparison, the cradle-to-grave (from field to end-use) system boundary is 0.7989 kg CO₂e kg⁻¹ biodiesel.

The carbon footprint of biodiesel produced by the Philippine CBP is lower than that of most biodiesel produced in other regions, including Brazil (South America), Indonesia, and the USA, with a cradle-to-gate emission of 0.7805 kg CO₂e per kg of biodiesel. The only exception is soybean methyl ester from the USA, which has a lower emission of 0.5370 kg CO₂e per kg of biodiesel.

Hotspot Analysis

A hotspot analysis was observed from the network generated from SimaPro (**Figure 2**). The carbon footprint network of materials, processes, and activities to produce 1 kg of biodiesel was outlined. The contributions of each

As shown in the network, the hotspot highlights the components contributing significantly to GHG emissions: combustion of bituminous coal at the RBD oil refinery to meet steam requirements; combustion of bituminous coal at the biodiesel refinery for steam generation; the indirect carbon footprint from producing and delivering methanol to the company; the indirect carbon footprint associated with the production and delivery of the catalyst used in the company's coco-biodiesel production; and the production of copra (**Figure 3**).

Sensitivity Analyses

Carbon footprint and GHG emission reduction base case (economic allocation) sensitivity to the scenario if energy allocation is applied. Since it is still a debate which allocation method is preferred over the other, a comparison of the carbon footprint and GHG reduction results of the base case employing economic allocation

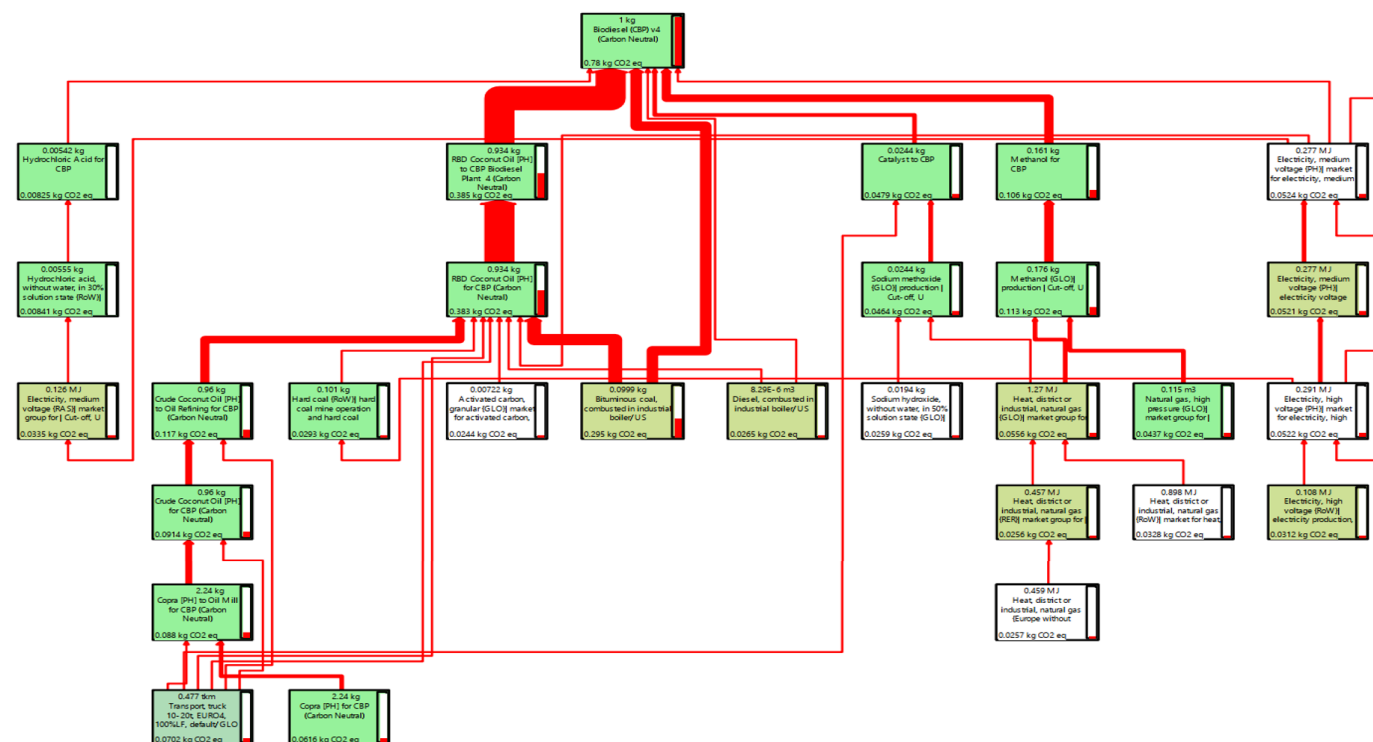


Figure 2. The network of components and their contribution to the total carbon footprint of CBP coco-biodiesel for hotspot analysis (2.8% cut-off).

(SimaPro preference) to the scenario wherein energy allocation is considered, was conducted to investigate the potential deviation of the carbon footprint results depending on the allocation method used. Only energy allocation was compared to the base case (economic allocation) and not mass allocation because energy allocations are commonly applied for energy and transport fuels.

A 3.59% (0.68317 from 0.70858 kgCO₂e L⁻¹) decrease in carbon footprint in kg CO₂e L⁻¹ is obtained if energy allocation was used (**Figure 4**). It equates to 78.68% GHG emission reduction, compared with the 77.89% using economic allocation (base case).

Sensitivity study on the carbon footprint and GHG emission reduction with different upstream biodiesel production scenarios. Two major case scenarios were considered in the upstream biodiesel production of CBP coco-biodiesel. First is the consideration that nut yields across the Philippines are varying. Therefore, the sensitivity of the base case (70 nut yield per tree per annum) to lower nut yield (Case A) and higher nut yield (Case B) scenarios was assessed.

Sensitivity analysis implies that lower nut yield (about 50 nuts per tree per annum) would increase the carbon footprint of the base case to about 1% (**Figure 5**). In general, on the same plant capacity, increasing the nut yield would reduce hectare requirement, hence a reduction in carbon footprint is expected. However, an opposite result is revealed upon raising the nut yield to 90 nuts per tree per annum, wherein about 40% increase in the carbon footprint was observed. This is due to the fertilization requirement to increase the nut yield to 90 nuts per tree per annum. The PCA recommends the fertilization standard of 1.5 kg per tree of ammonium sulfate and 2 kg per tree of NaCl. The increase in yield by using ammonium sulfate did not compensate for its direct and indirect GHG emissions. Nevertheless, even if the farming practices were improved and used the recommended fertilizers, which will increase the carbon footprint of the local biodiesel production to 0.9444 kg CO₂e (kg biodiesel)⁻¹, it is still superior to most of the biodiesel production of other countries, except again for the US soybean and tallow ME.

Another consideration in the upstream scenario were the sources of crude CNO of the RBD oil refinery (source of RBD of CBP) to depict possible scenarios since CNO sources could vary from time to time. Five case scenarios were assessed to investigate the effect of varying supplier location or distance to the refining facility and the mode of transportation. These case scenarios, namely Cases C,

D, E, F and G assumed that crude CNO supply of RBD oil refinery was solely sourced from that one location, where coconut and copra producers were commonly found.

A slight decrease from the base case carbon footprint was observed for Case C (148 km distance via land transport). Case D (431 km distance via land transport) increases the base case carbon footprint by about 4.37% (from the base case utilizing both land and sea transport) (**Figure 6**). It can also be deduced that although the absolute distances of the first two locations in Case C and D were shorter, the mode of transportation in Cases E, F, G, which was via barge or sea transport (port to port) lowered the carbon footprint of biodiesel by 2.01% for Case E, 2.08% for Case F, and 1.51% for Case G than that of the base case. Note that land travel from site location to ports and vice versa were also considered for Cases E, F, and G.

Chemical Refining for RBD Production

In chemical refining, the moisture content of the oil is first reduced through drying. Then, sodium hydroxide solution is added to the oil to convert the free fatty acid to soap. The materials in the inventory included phosphoric acid, sodium hydroxide, coal for the steam requirement, electricity requirements and the transportation of RBD to the CBP facility. The RBD oil yield per kg CNO is 96% (Demafelis *et al.* 2019).

The delivery of RBD oil to CBP remains to use the transport truck database in SimaPro 9.0.0.49, truck >20t, EURO4, 100%LF, empty return/GLO Energy. Carbon dioxide emissions from wastewater produced in oil refining were not accounted for as it is part of the carbon neutrality concept.

Economic Allocation (RBD, chemical refining)

Soap is a by-product of the chemical oil-refining process with economic value. The economic allocation factor for RBD oil produced from chemical refining is computed to be 0.9654, which is used to distribute the total carbon footprint of RBD production to RBD oil.

With this value, the carbon footprint of refined, bleached, deodorized (RBD) oil amounted to 0.17822 kg CO₂e L⁻¹ biodiesel. This carbon footprint up to RBD production was 47.35% lower compared to the RBD using physical refining, which had a carbon footprint of 0.33987 kg CO₂e L⁻¹ biodiesel. The GHG emission reduction of CBP's biodiesel if chemical refining was applied goes up to 82.91% from 77.89% of physical refining (L L⁻¹).

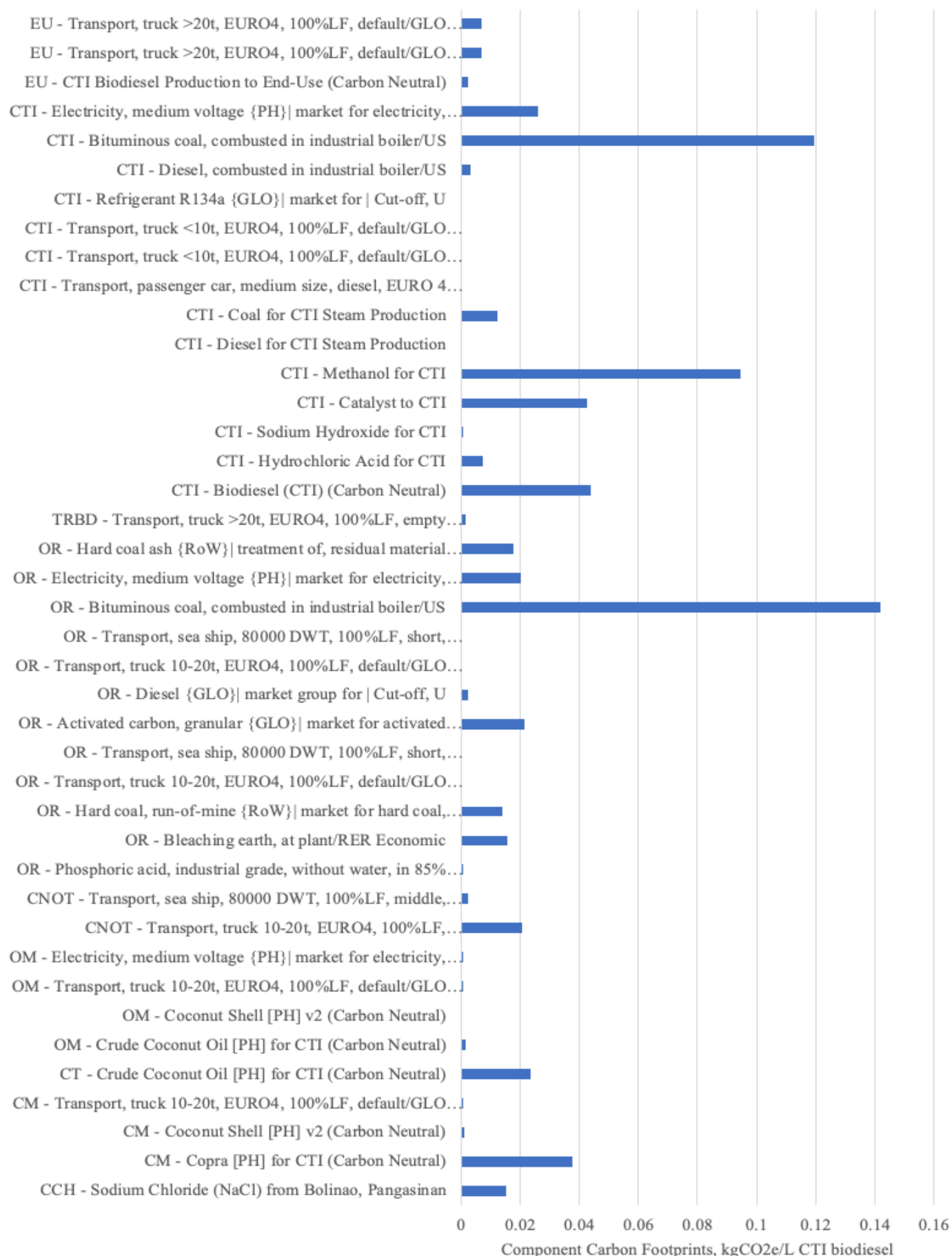


Figure 3. Hotspot analysis of the components contributing to the total carbon footprint of CBP coco-biodiesel.

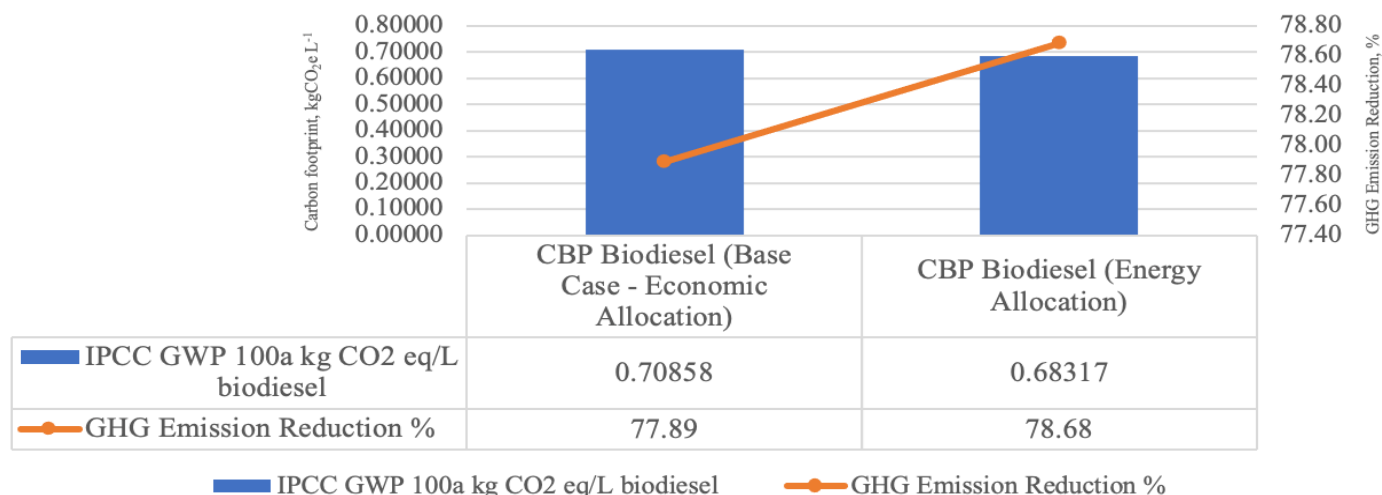


Figure 4. Carbon footprint of Philippine coco-biodiesel and GHG emission reduction compared to the base case (economic allocation) sensitivity if energy allocation is applied.

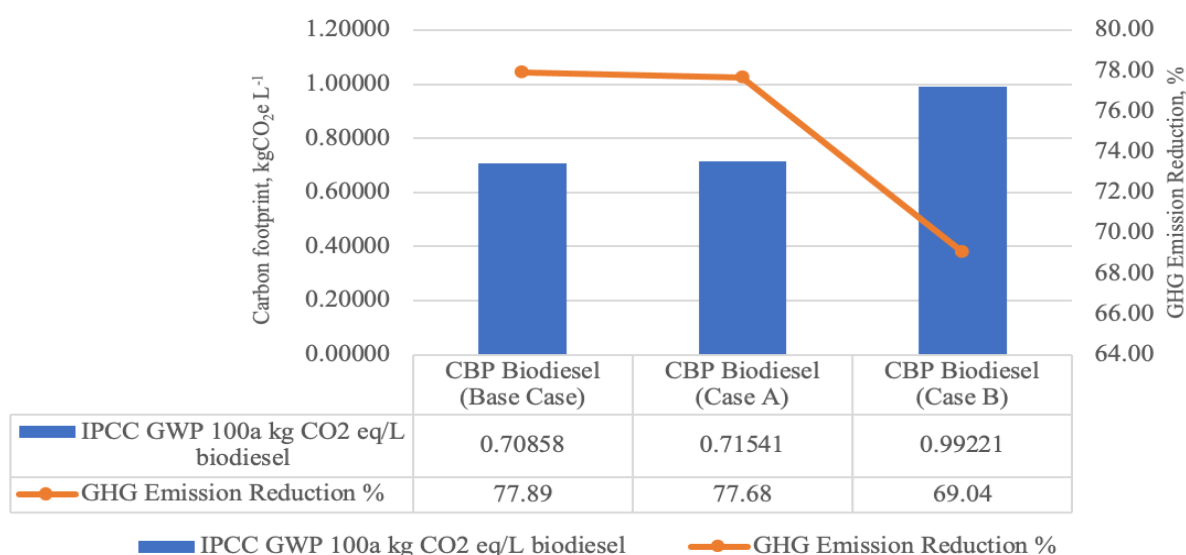


Figure 5. Sensitivity analysis on the carbon footprint and GHG emission reduction of the base case to lower and higher nut yield case scenarios.

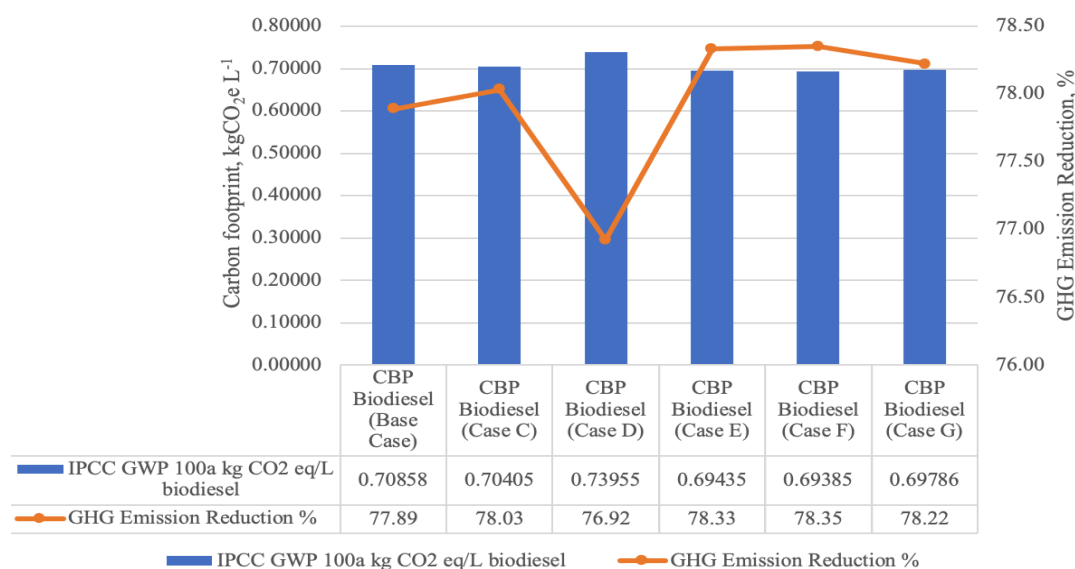


Figure 6. Sensitivity analysis on the carbon footprint and GHG emission reduction considering different locations of CNO suppliers of the RBD oil refinery.

CONCLUSIONS AND RECOMMENDATIONS

Carbon life cycle inventory and global warming potential (GWP) 100a impact assessment of CBP coco-biodiesel within the defined system boundary estimated that the carbon footprint of CBP coco-biodiesel of about 0.78050 kg CO₂e kg⁻¹ (cradle-to-gate; distribution and end-use excluded to reduce variation when compared) was lower compared to that biodiesel produced from most of the top biodiesel-producing countries: 0.98 kg CO₂e kg⁻¹ for soy biodiesel from Brazil; 2.893 kg CO₂e kg⁻¹ for palm biodiesel from Indonesia; and 1.57-2.5985 kg CO₂e kg⁻¹ for the biodiesels in Europe. It had, however, a slightly higher emission compared to the tallow biodiesel and soy biodiesel from the US, which emits 0.697 and 0.537 kg CO₂e kg⁻¹ biodiesel, respectively.

In comparison to the carbon footprint of fossil-derived diesel, the GHG reduction potential of CBP coco-biodiesel was about 77.89% (L L⁻¹ basis) compared to diesel. This study proves that the consumption of biodiesel will contribute to the environmental pledge of the country. If 100% of the total biodiesel demand is assumed to have the same carbon footprint, the biodiesel for on-road use in 2021 (*Mojica-Sevilla 2022*) at 2.6% blending rate, had an effective GHG emission reduction in the transportation sector that uses diesel, equivalent to 1.94%. When blending increases to 5% (B5), this industry can expect a GHG reduction of 3.89%, which is attainable with the coconut supply and the rated production capacity of existing biodiesel refineries. This satisfies the unconditional target of the Philippines for GHG reduction of 2.71%, if implemented to be attained by every industry, at the minimum.

By exploring other possible upstream case scenarios in the coco-biodiesel production, targeting higher nut yield by applying the recommended fertilizer application rate from the Philippine Coconut Authority (PCA) would result to a significant increase in the carbon footprint due to the indirect and direct field emission of the fertilizer, which in a typical coconut cultivation scenario in the Philippines is not being applied. Moreover, lower nut yield scenario will also increase CBP coco-biodiesel's carbon footprint by only 1%. It is recommended for future studies to investigate how the yield can be optimized through better agricultural management without significant changes in fertilizer application.

Other than optimizing agronomic yields in reducing the carbon footprint of CBP coco-biodiesel production, another recommendation derived from life cycle assessment is to consider different types of processing. In

this study, it was observed that chemical refining of CNO resulted in a lower carbon footprint than the physical refining. It was notable from the sensitivity analysis that sea transport resulted in a lower carbon footprint than land transport per Mg-km.

Biomass could also be explored as fuel in generating the steam requirement of both CBP coco-biodiesel and RBD oil refining to further reduce the biodiesel carbon footprint as biomass is part of the carbon-neutral cycle.

REFERENCES

- Argonne National Laboratory. 2021. The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model. U.S. Department of Energy, USA.
- Asian Development Bank. 2017. Pathways to Low-Carbon Development for the Philippines. Asian Development Bank Philippines <http://dx.doi.org/10.22617/TCS179189-2>
- Biotechnology Industry Organization. 2015. The Renewable Fuel Standard: A Decade's Worth of Carbon Reductions. Retrieved from <https://www.bio.org/sites/default/files/legacy/bioorg/docs/RFS%2010%20Year%20GHG%20Reductions.pdf>.
- Board of Investments. 2011. Philippine Biofuels. Retrieved from <https://boi.gov.ph/wp-content/uploads/2018/02/Bio-Fuels.pdf>
- Brandão, M., Kirschbaum, M. U., Cowie, A. L., and Hjuler, S. V. 2018. "Quantifying the Climate Change Effects of Bioenergy Systems: Comparison of 15 Impact Assessment Methods". *Wiley GCB Bioenergy* 727-743.
- Brandão, M., Azzi, E., Novaes, R. M., and Cowie, A. 2021. "The Modelling Approach Determines the Carbon Footprint of Biofuels: The Role of LCA in Informing Decision Makers in Government and Industry". *Cleaner Environmental Systems* 2: 100027. <https://doi.org/10.1016/j.cesys.2021.100027>.
- Cavalett, O., Chagas, M., Seabra, J. E., and Bonomi, A. 2013. "Comparative LCA of Ethanol Versus Gasoline In Brazil Using Different LCIA Methods". *The International Journal of Life Cycle Assessment* 18:647-658 <https://doi.org/10.1007/s11367-012-0465-0>.
- Cerri, C. P., You, X., Cherubin, M., Moreira, C. S., Raucchi, G. S., Castigioni, B. d.A., Alves, P. A., Cerri, D. G. P., Melo, F. F. d. C., and Cerri, C. C. 2017. "Assessing the Greenhouse Gas Emissions of Brazilian Soybean Biodiesel Production". *PLoS ONE* 12(5): e0176948.
- ClimateWatch. 2022. Data Explorer. Retrieved from

- <https://www.climatewatchdata.org/data-explorer/historical-emissions?historical-emissions-data-sources=cait&historical-emissions-gases=co2&historical-emissions-regions=All%20Selected%20CPHL&historical-emissions-sectors=total-including-lucf%20transportation%20>
- Dar, W. 2019. PH Coconut Industry a ‘Sleeping Giant’. Retrieved from Philippine Coconut Authority: <https://pca.gov.ph/index.php/10-news/237-ph-coconut-industry-a-sleeping-giant>
- Dayrit, F. M., Buenafe, O. M., Chainani, E. T., de Vera, I. S., Dimzon, I. D., Gonzales, E. G., and Santos, J. R. 2007. “Standards for Essential Composition and Quality Factors of Commercial Virgin Coconut Oil and its Differentiation from RBD Coconut Oil and Copra Oil”. *Philippine Journal of Science* 136(2): 119-129.
- Demafelis, R.B., Magadia, B. T., and Gatdula, K. M. 2020. “Carbon Footprint and Climate Change Mitigation Potential of Cocobiodiesel in the Philippines”. *Philippine Journal of Crop Science* 45(3): 28-36.
- Demafelis, R.B., Dizon, L.S.H., Gatdula, K.M., Rudolfo Jr., V.A., Magadia, B.T., and Asuncion Jr., R.V. 2019. “Life Cycle Assessment in Terms of Carbon Debt and Payback Period Analyses, Carbon Savings, and Energetics Studies of Biodiesel Production from Coconut Oil in the Philippines”. A Terminal Report submitted and accepted by Department of Energy – National Biofuels Board (DOE-NBB)
- Department of Energy [DOE]. 2024a. DOE mandates higher biodiesel blend beginning October 2024. Retrieved from <https://doe.gov.ph/press-releases/doe-mandates-higher-biodiesel-blend-beginning-october-2024>
- Department of Energy [DOE]. 2024b. Guidelines on biofuel blend implementation. Retrieved from https://doe.gov.ph/sites/default/files/pdf/issuances/DC2024-05-0014_0.pdf
- Engineering ToolBox. 2008. Fossil vs. Alternative Fuels - Energy Content. https://www.engineeringtoolbox.com/fossil-fuels-energy-content-d_1298.html
- Intelligent Energy Europe. 2015. Biograce I Harmonised Calculations of Biofuel Greenhouse Gas Emissions in Europe. Europe.
- ISO 14040:2006. Environmental Management – Life Cycle Assessment – Principles and Framework.
- Javier, E. Q. 2015. Modernization of the Coconut Industry. Retrieved from The National Academy of Science and Technology, Philippines: [https://www.nast.ph/images/pdf%20files/Publications/Bulletins/NAST%20](https://www.nast.ph/images/pdf%20files/Publications/Bulletins/NAST%20Bulletin%20no.%208%20-%20Modernization%20of%20the%20Coconut%20Industry.pdf)
- Bulletin%20no.%208%20-%20Modernization%20of%20the%20Coconut%20Industry.pdf
- Jeswani, H. K., Chilvers, A., and Azapagic, A. 2020. “Environmental Sustainability of Biofuels: A Review”. *Proceedings of the Royal Society A: Mathematical, Physical, and Engineering Science* 47620200351
- Liu, Y., Cruz-Morales, P., Zargar, A., Belcher, M. S., Pang, B., Englund, E., Dan, Q., Yin, K., and Keasling, J. D. 2021. “Biofuels for a Sustainable Future”. *Cell* 184(6):1636-1647 <https://doi.org/10.1016/j.cell.2021.01.052>.
- Mojica-Sevilla, F. 2022. Biofuels Annual. Philippines: USDA FAS Global Agricultural Information Network.
- Mojica-Sevilla, F. 2023. Biofuels Annual. Philippines: USDA FAS Global Agricultural Information Network.
- Moreno, M. L., Kuwornu, J. K. M., and Szabo, S. 2020. “Overview and Constraints of the Coconut Supply Chain in the Philippines”. *International Journal of Fruit Science* 20(sup2), S524–S541. <https://doi.org/10.1080/15538362.2020.1746727>
- National Renewable Energy Laboratory [NREL]. 1998. Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus. United States: <https://www.nrel.gov/docs/legosti/fy98/24089.pdf>.
- Obligado, A., Demafelis, R.B., Matanguihan, A.E.D., Villancio, V., Magadia, Jr, R., and Manaig, L. 2017. “Carbon Emission Inventory of a Commercial-Scale Jatropha (*Jatropha curcas* L.) Biodiesel Processing Plant”. *Journal of Environmental Science and Management Special Issue* (1):20-32 https://doi.org/10.47125/jesam/2017_sp1/03.
- Pereira, L., Cavalett, O., Bonomi, A., Zhang, Y., Warner, E., and Chum, H. 2019. “Comparison of Biofuel Life-cycle GHG Emissions Assessment Tools: The Case Studies of Ethanol Produced from Sugarcane, Corn, and Wheat”. *Renewable and Sustainable Energy Reviews* 110:1-12.
- Philippine Coconut Authority [PCA]. 2019a. Philippine Coconut and Oil Palm Commodity Prices, Monthly Average for June 2019. Retrieved from <https://pca.gov.ph/pdf/cpw/ave/june.pdf>
- Philippine Coconut Authority [PCA]. 2019b. Average Copra Price. Retrieved from https://pca.gov.ph/pdf/cpw/copra/2019/june/2018_2019JuneMonthlyCopraPrice.pdf
- PRé Sustainability. 2019. SimaPro v.9.0.0.49 [Software]. PRé Sustainability. <https://simapro.com>
- Raghavan, K. 2010. Biofuels from Coconuts. Retrieved from

- https://energypedia.info/images/f/f9/EN-Biofuels_from_Coconuts-Krishna_Raghavan.pdf
- Resources Institute and World Business Council for Sustainable Development. 2011. Greenhouse Gas Protocol – Product Life Cycle Accounting and Reporting Standard. ISBN 978-1-56973-773-6
- Ritchie, H. 2020. Cars, Planes, Trains: Where Do CO₂ Emissions from Transport Come From? Retrieved from University of Oxford Our World in Data: <https://ourworldindata.org/co2-emissions-from-transport>
- Srikumar, K., Tan, Y., Kansedo, J., Tan, I., Mujawar Mubarak, N., Ibrahim, M.,M., Nai Yuh Yek P., Chee Yew Foo, H., Karri, R.R., and Khalid, M. 2024. “A Review on the Environmental Life Cycle Assessment of Biodiesel Production: Selection of Catalyst and Oil Feedstock”. *Biomass and Bioenergy* 185 ISSN 0961-9534.
- Swain S., M. Din, R. Chandrika, G.P. Sahoo and S. Dam Roy. 2014. “Performance Evaluation of Biomass Fired Dryer for Copra Drying: A Comparison with Traditional Drying in Subtropical Climate”. *Food Processing and Technology* 5(1):294
- Tan, R. R., Culaba, A. B., and Purvis, M. R. 2004. “Carbon Balance Implications of Coconut Biodiesel Utilization in the Philippine Automotive Transport Sector”. *Biomass and Bioenergy* 26(6): 579-585.
- United Nations Environment Programme. 2018. The Emissions Gap Report 2018. Nairobi: United Nations Environment.
- Unglert, M., Bockey, D., Bofinger, C., Buchholz, B., Fisch, G., Luther, R., Krah, J. 2020. “Action Areas and the Need for Research in Biofuels”. *Fuel* 268 117227 ISSN 0016-2361 <https://doi.org/10.1016/j.fuel.2020.117227>.
- US Environmental Protection Agency. 2014. Emission Factors for Greenhouse Gas Inventories. Retrieved from https://www.epa.gov/sites/default/files/2015-07/documents/emission-factors_2014.pdf.
- Varanda, M. G., Pinto, G., and Martins, F. 2011. “Life Cycle Analysis of Biodiesel Production”. *Fuel Processing Technology* 92(5):1087-1094.
- Wahyono, Y., Hadiyanto, H., Budihardjo, M., and Adiansyah, J. 2020. “Assessing the Environmental Performance of Palm Oil Biodiesel Production in Indonesia: A Life Cycle Assessment Approach”. *Energies* 13: 3248: doi: 10.3390/en13123248.
- Wang, M., Han, J., Dunn, J. B., Cai, H., and Elgowainy, A. 2012. “Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Ethanol from Corn, Sugarcane, and Cellulosic Biomass for US Use”. *Environmental Research Letters* 7(4):45905-13 <https://doi.org/10.1088/1748-9326/7/4/045905>.
- Xu, H., Ou, L., Li, Y., Hawkins, T. R., and Wang, M. 2022. “Life Cycle Greenhouse Gas Emissions of Biodiesel and Renewable Diesel Production in the United States”. *Environmental Science and Technology* 56(12):7512-7521.
- Yani, M., Toruan, D., Puspaningrum, T., Sarfat, M., and Indrawanto, C. 2022. “Life Cycle Assessment of Coconut Oil Product”. IOP Conference Series: Earth and Environmental Science 10.1088/1755-1315/1063/1/012017.