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Carbon Emission Inventory of a Commercial-Scale *Jatropha* (*Jatropha curcas* L.) Biodiesel Processing Plant

ABSTRACT

Biofuel feedstock development is in limelight because of its pronounced capability to reduce greenhouse gas emissions (GHG). The move towards renewable energy intensified researches to provide concrete attestations that could be benefited from the effort. This research assessed the GHG reduction potential of biodiesel produced from Jatropha curcas L., relative to that of the conventional petroleum diesel. Computations were based on a standard 30-MLPY biodiesel plant with a co-generation facility, utilizing the byproducts of the process for electricity production. The GHG emissions were standardized and presented as equivalent carbon dioxide emission (CO_2e). The boundary set for the analysis was from cradle to grave, considering the life-cycle from the production of the feedstock to the production of biodiesel, and eventually, its end-use. The Life Cycle Assessment (LCA) resulted to a negative net carbon footprint due to the carbon dioxide sequestration capability of the Jatropha plants. The whole system has a net CO_2e footprint equivalent to 1,706,365.26 Mg CO_2e a^{-1}. Without considering the carbon dioxide absorbed by the plants, LCA of Jatropha biodiesel is still about 25% cleaner than petroleum diesel fuel. With sequestration, the GHG emission reduction can go as high as 548.38%. With the current Philippine biodiesel blending of 2%, if Jatropha methyl ester was used for the blending, this study shows that emission can be cut by 11%. And with increase in the blending, a more positive amount of savings will be achieved, which if at B100, savings could go as high as 581.18%.

Key words: *carbon inventory, carbon payback, GHG emission reduction, Jatropha biodiesel, Jatropha methyl ester*

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INTRODUCTION

Renewable energy production has been a cutting-edge movement throughout the world since the Fourth Wave Era of Environmental Conservation. Today, the global climate conditions continue to worsen because of the anthropogenic greenhouse gas (GHG) emissions. In the Philippines, the energy and transport sector accounts for 52% of the total domestic emissions; agriculture 31%; waste 10%; and industrial processes 7% (*CCC 2016*). This buildup of GHG in the atmosphere, produced not only domestically but largely by the leading countries, caused global warming, which then causes climate change.

As party to the Kyoto Protocol, the Philippines has legislated the Biofuels Act of 2006 (Republic Act 9367) and Renewable Energy Act of 2008 (RA 9513). Implementation of these laws comes with incentives to encourage investments in renewable energy. Hence, this study aims to reduce harmful emissions to have a balanced economic growth and development while protecting the peoples' health and the environment.

While Philippines is recognized as a global leader in renewable energy (RE) use and production (*Corpuz 2013*). Compared with other countries within the ASEAN-6, the Philippines has the highest share of modern renewable energy in its total primary energy supply (TPES) with 25%, followed by Thailand with only 11% (IRENA & *ACE 2016*). However, it is necessary to increase its capacity for renewable energy for the vision of long-term energy sufficiency and environmental sustainability.

Environmental sustainability in terms of pollution creation can be assessed by conducting a life-cycle assessment (LCA). The procedure involves identification, quantification, and evaluation of the impacts of a product, service, or activity within a specified system boundary. The LCA can focus on carbon, water, or energy footprint. In this study, a carbon footprint inventory was done for a biodiesel processing plant from cradle-to-grave, or from the production of feedstock to the final products' end-use, using an alternative agricultural crop to assess how the system compares with petroleum diesel fuel in terms of its GHG emission.

Biodiesel is a processed diesel-equivalent fuel which can be derived from organic matter. It can be used purely or in some volume percentage, usually 2-20% (v/v) with petroleum diesel, depending on the amount allowed by the diesel engine manufacturers. Following the international standards on conventional diesel fuel (ASTM D975), low-level blends (concentrations of up to B5), can also be called diesel fuel and is approved for safe usage of any compression-ignition engines (*AFDC-US DOE 2016*).

The Philippines currently produces biodiesel primarily from coconut oil, sufficient for domestic use at a current blend of 2% (B2). Since 2007, the country mandated fuel blending in accordance with the Philippines Biofuels Act of 2006, which was set at 1% initially. It was increased to 2% in 2009 but has not been increased further from that time even though an increase to 5% was planned as presented in the 2013-2030 National Biofuels Plan of the Department of Energy of the Philippines (*PEP 2012-2030*). Currently, there are 11 biodiesel producers in the country with a total registered capacity of 584.9 ML. Increasing the blending to 5% projects a biodiesel supply requirement equivalent to 358.82 ML (using 2016 data demand for diesel) (*DOE 2016, personal communication*), which means domestic production can still meet the demand if blending was increased. However, it is hindered because of pricing concerns for coconut (*ISAAA 2014*).

Future goals to increase the use of biofuels will impose demands for a larger volume in and out of the country. Even though coconut oil supply may suffice for the domestic biodiesel requirement, development of other feedstocks for biodiesel production still needs to be considered because coconut oil has other more meaningful final products, especially in the food industry. Other countries use different production feedstocks. For instance, in Europe, the primary biodiesel feedstock is rapeseed; soybeans in the US; and palm oil in most parts of Asia (*Uriarte and Culaba* (*eds.*) *2008*). However, since these feedstocks are mostly food crops, any amount used for energy production means reduction on food supply. Sooner or later, as the demands increase, the competition between food and fuel feedstock will be problematic. In response, devotion to developing feed stocks, which will not compete with food and can thrive in marginal lands, has been strengthened. This study focused on the production of biodiesel from *Jatropha curcas* L.

Jatropha is a second-generation feedstock, which has the ability to grow on marginal soils and idle lands,requiring minimal amount of water (*Villancio et al. 2012*).

However, although *Jatropha* can thrive on marginal lands and on minimal water supply, the plant will not achieve optimal yields with these unfavorable conditions (*Beaver et al. 2016*). The technical viability of *Jatropha* methyl ester (JME) has already been successfully demonstrated (*Rao et al. 2009*). However, after a number of researches and analyses, the viability of *Jatropha* as biodiesel feedstock was challenged. A previous report (*von Maltitz et al. 2014*) stated that *Jatropha* cannot compete as a biodiesel feedstock because the actual practice has not achieved financially viable yields and it is labor-intensive especially in picking fruits. As it is projected to be grown in remote rural areas, transportation cost then becomes a problem. Nevertheless, the study presents the potential of *Jatropha* methyl ester to mitigate climate change, even if it may not economically attractive at present.

This research aims to quantify carbon emissions from production to the end-use of *Jatropha* biodiesel compared to the conventional petroleum diesel. The life cycle analysis of *Jatropha* methyl ester was presented, mostly utilizing local information for the crop from seedling production and planting. A design of the construction of the facility and the process for biodiesel production were done for this study. The study also included the use of co-products such as husk and seed cake for power production.

MATERIALS AND METHODS

Evaluations were made from the feedstock production to end-use. Four main areas of *Jatropha* biodiesel life cycle were taken into consideration for carbon inventory. The boundaries for these areas are feedstock production, plant construction, plant operation, and biodiesel end-use (**Figure 1**).

Method Description

A detailed procedure for the production of biodiesel from *Jatropha* was designed to account all the sources and sinks of carbon. Initially, material and energy balances were established. Material balance takes account of all the amounts of feedstock, chemical requirements, and other materials, which all have corresponding carbon emissions. On the other hand, the energy balance determines heat transfers and the amount of electricity that the operation uses, of which generation emits GHGs. The emission factors used are recognized to be the carbon dioxide equivalent of the total GHG emission of the material/process.

The boundary considered was from cradle-to-grave, or from the production of feedstock to its conversion to biodiesel, and to the end-use of biodiesel. The sources comprise of the materials that have their equivalent embedded carbon emission and the processes which directly emit CO_2e (**Figure 1**). Included in the sources are: the establishment of nursery and the construction of the facility; materials used and burned in the plantation and the process; the fuel for transportation of materials; and the burning of biodiesel. The CO_2e emitted in the establishment of nursery and the construction of the facility were considered "carbon debt." The sinks, on the other hand, are the elements that present carbon dioxide savings, which in this case are the carbon sequestering capacity of the Jatropha plants, and the opportunity savings from producing excess electricity in the facility that could be sold to the grid and replace some load that could have been generated from coal-fired power plants, which have higher emission intensity. These savings can be used to "pay off" the carbon debt accumulated, hence implying a "payback period."

Carbon Debt. Carbon debt implies the amount of carbon emission contribution of the system even before operation starts, just like capital investment only in terms of carbon. In this case, nursery establishment and plant construction were included to have contributed to the carbon debt.

Payback Period. The carbon payback period is the duration when the carbon debt can be offset by the savings from the carbon sinks. Payback period is only possible if savings is larger than the carbon debt.

The basis of computation was a commercial-scale production plant with a 30 MLPY capacity and the functional unit used to report GHG emissions is the amount of carbon dioxide equivalents (CO_2e) emitted in the production of the annual capacity.

Inventory Process, Data and Assumptions

The data gathered from the local research reported in the handbook, "*Jatropha* Production and Processing Manual" (*Villancio et al. 2012*) were adopted in this study. Furthermore, some of the data for compositions of materials during processing were actual data observed from the laboratory experiment done in the Department of Chemical Engineering, University of the Philippines Los Baños (UPLB).

Three periods were considered in the life cycle: Year 0, when the nursery was established and then the seedlings were transplanted after two months; Year 1, when the plantation was maintained and the construction of the processing facility was accomplished; and Year 2, when the *Jatropha* plantation has achieved a conservative

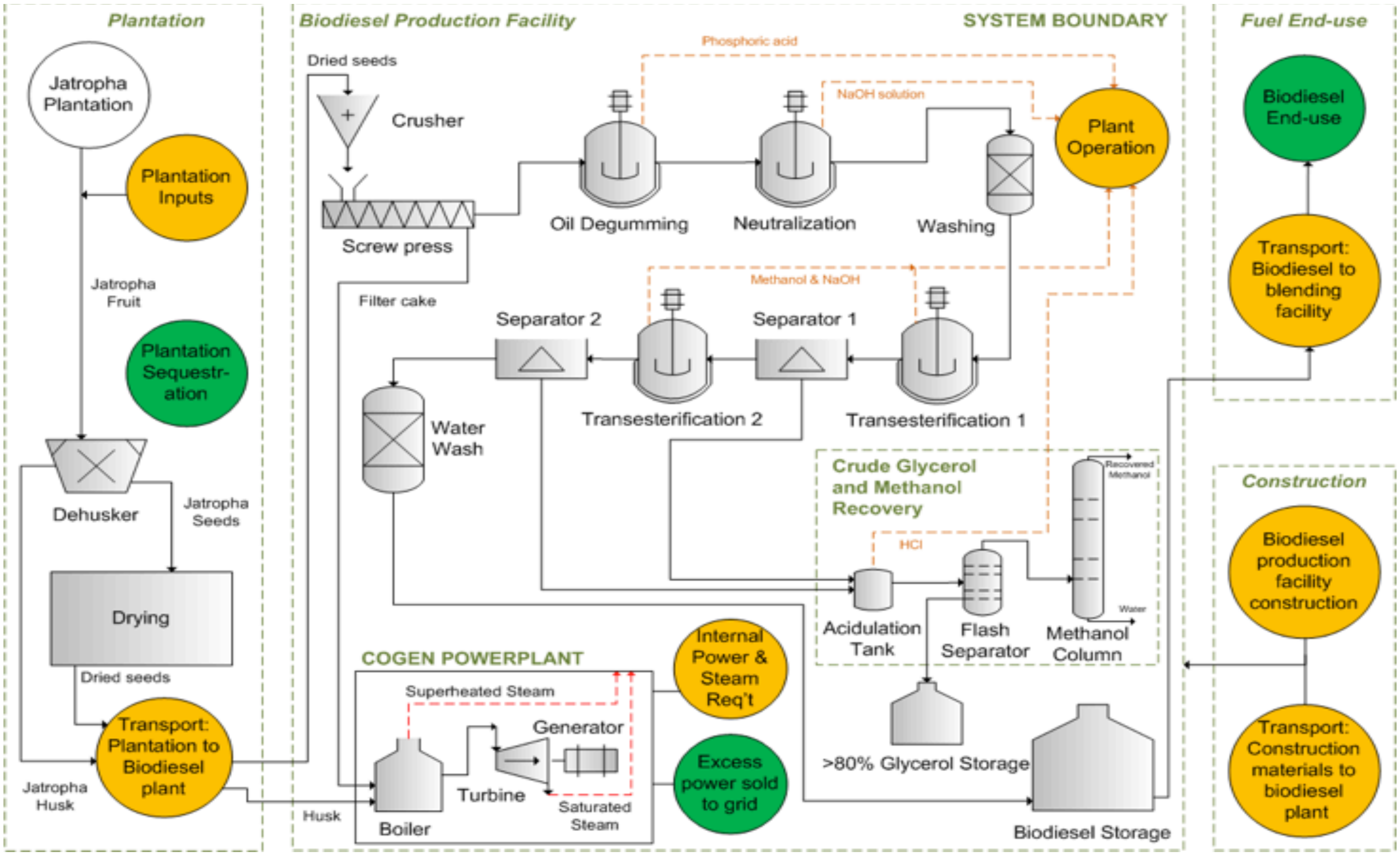

Figure 1. System boundary and GHG sources of Jatropha methyl ester production.

yield that could supply enough feedstock for the processing plant to operate.

Year 0: Nursery Establishment and Transfer to Plantation

Nursery establishment. Establishment of a nursery was necessary for the first phase of feedstock production. The total number of seedlings was computed based on the total capacity of the processing plant and the assumed average annual yield (**Table 1**). It was assumed that the nursery was located near the plantation and that no fertilizer was applied because the soil, which was well-drained sandy loam soil to clay loam, was favorable for healthy growth (*Villancio et al. 2012*). Seedlings were assumed to be grown in polyethylene bags with soil composition of 1-1-1 local soil, sand, and compost (*The Jatropha Organisation of South Africa 2008*).

The emissions from the establishment of *Jatropha* nursery for raising Jatropha seedlings came primarily from the use of PE bags, computed based on its embedded carbon emission (**Table 2**).

Plantation. After two months in the nursery, the seedlings were transplanted at 2,500 planting density per hectare (2 x 2 m planting configuration). Land preparation and weeding was assumed to be done mechanically, consuming diesel at 93 L ha^{-1} (*Boonkum et al. n.d.*) (**Table 1**). Inorganic fertilizers, such as urea, superphosphate, and muriate of potash were applied. The total land area computed, based on the processing facility capacity, was purely hypothetical and a definite distance of 50 km from the facility was assumed. Furthermore, it was assumed that there was no land-use change. Weeding was assumed to be done every two months by labor. Meanwhile, in order to manage *Jatropha* pests, it was assumed that no pesticides were used; instead, pest management relied on biological control agents for *Jatropha* pests as suggested by *Villancio et al.* (*2012*), such as ladybird beetles, scelionid wasp, spider, and some species of fungi. Lastly, a monocrop plantation was assumed. During this initial stage, harvest amounts to 600 kg ha^{-1} (*Villancio et al. 2012*), but these were not processed.

The sources of carbon emission during the first year were: the embedded carbon of LDPE bags; and the emission from fuel combustion. Also, during this period, there is already a carbon sink because of the growing Jatropha plants, which are able to sequester carbon dioxide. Since local data for the sequestration capability of *Jatropha* are not available an actual field data in Malaysia by *Firdaus et al.* (*2010*) were used. Even though their planting configuration differs (2 x 3m, 1,666 plant density ha^{-1}), the data were not adjusted because individual characteristics

Table 1. Agricultural and processing activities and the sources of carbon dioxide emission.

Plantation Configuration	2 x 2 m
Planting Density	2,500 plants ha^{-1}
Year 0 – Nursery and Plantation	
Nursery	Unit
LDPE*	104,625,000 units
Plantation	
Land preparing and weeding[1]	93 L diesel ha^{-1}
Fertilizer[2]	
Urea	50 kg ha^{-1}
Superphosphate	300 kg ha^{-1}
Muriate of Potash	40 kg ha^{-1}
CO_2 soil emissions from urea application	0.2 kg C kg urea^{-1}
N_2O soil emissions from urea application	0.47 kg N kg urea^{-1}
Year 1 – Plantation and Facility Construction	
Plantation	
Weeding (Labor)	
Fertilizer[2]	
Urea	50 kg ha^{-1}
Superphosphate	300 kg ha^{-1}
Muriate of Potash	40 kg ha^{-1}
CO_2 soil emissions from urea application	0.2 kg C kg urea^{-1}
N_2O soil emissions from urea application	0.47 kg N kg urea^{-1}
Facility Construction	
Materials*	
Galvanized Sheet	26.91Mg
Steel	2,105.59 Mg
Concrete	10,762.17 Mg
Stainless Steel	69.11 Mg
Gravel	4,685.36 Mg
Transport of Materials*	3,544 trips
Year 2 – Operation of the Whole System	
Plantation	
Weeding (Labor)	
Fertilizer[2]	
Urea	50 kg ha^{-1}
Superphosphate	300 kg ha^{-1}
Muriate of Potash	40 kg ha^{-1}
CO_2 soil emissions from urea application	0.2 kg C kg urea^{-1}
N_2O soil emissions from urea application	0.47 kg N kg urea^{-1}
Harvesting (via Labor)	
Dehusker3	0.008 L diesel ha^{-1}
Storage	
Woven PP bag	25 kg seeds per sack
Hauling*	33,480 trips a^{-1}
Facility Operation	
Transesterification*	
Phosphoric Acid	29,000 kg a^{-1}
Sodium Hydroxide	534,900 kg a^{-1}
Methanol	7,813,464 kg a^{-1}
Hydrochloric Acid	244,368 kg a^{-1}
Cogeneration*	
Seedcake for combustion for power generation	59,889,952.80 kg a^{-1}
Jatropha husk for combustion for power generation	68,442,857.76 kg a^{-1}
Electricity	3,300,000.00 kg husk a^{-1}
Transportation of biodiesel to blending facility*	3,000 trips a^{-1}

[1]*Boonkum et al. n.d.*; [2]*Villancio et al*. 2012; [3]*FACT Foundation 2010*

*Data are based on the result of the analysis

Table 2. Emission factors of materials in plantation.

Fertilizer[1]	**kg kg^{-1} material**
Urea	3.152
Superphosphate	0.095
Muriate of Potash	0.307
Carrier bags[2]	**kg CO_2/kg bag**
LDPE	6.924
Woven PP bag	23.088

[1] Biograce GHG Calculation Tool Standard Values; can be retrieved from http://www.biograce.net/content/ghgcalculationtools/standardvalues;

[2] Symphony Environmental; can be retrieved from http://www.d2wusa.com/files/CarbonFootPrintofPlasticBags.pdf

such as plant height, leaf area, the number of fruits per plant, and number of seeds per plant decrease as the planting density is increased (*de Lima et al. 2016*), hence assuming an approximately equal amount of total carbon in biomass per hectare for 10-month old plants of 1.47 Mg ha^{-1} or 5.39 Mg CO_2 ha^{-1} (**Table 3**). Although lower data were obtained in Senegal, West Africa by *Diédhiou et al.* (*2017*) with one-year old Jatropha plant, 0.27 Mg ha^{-1}, equivalent to about 1 Mg CO_2 ha^{-1}, and in Patancheru, India with 0.31 Mg ha^{-1}, equivalent to about 1.14 Mg CO_2 ha^{-1} (*Wani et al. 2012*), the authors opted to use the data from Malaysia for the inventory due to geographical precision.

Year 1: Plantation Maintenance and Facility Construction

Plantation. The plantation was maintained by pruning and weeding by labor. Fertilization was applied using the same rates as in Year 0. During the second year, seed harvest amounts to 2,000 kg ha^{-1}, which is still insufficient to supply the annual yield requirement. Nevertheless, the plants were able to sequester 38.225 Mg CO_2 ha^{-1} (**Table 3**).

Facility Construction. Using the material and energy balances, sizes of equipment were determined and the whole production plant was laid out. From this, an account for the construction materials was calculated. Carbon emissions were calculated using the “embodied carbon” or the total CO_2e released over the life cycle of the material. The sum of the materials was derived from building the facilities and fabrication of equipment. The bill of materials for the construction of the facility includes components for the roofing system, wall and framings, flooring, beams and girders, staircases, hand railings, bracings while the assembly of the equipment in the plant includes base support, pipes and pumps. The materials are assumed to be transported from a 50-km distance using a heavy-duty truck with a hauling capacity of 10 Mg and has a fuel economy equivalent to 2.126 km L^{-1} (*ANL 2014*). The data on carbon emission factors for construction materials were obtained from the Inventory of Carbon and Energy (ICE) (*Hammond and Jones 2011*) (**Table 4**).

Table 3. Total carbon and carbon dioxide in biomass (Mg ha^{-1}).

Age months	Total C in biomass (2x3)[1] Mg ha^{-1}	Total CO_2 sequestered* Mg ha^{-1}
32	13	47.67
17	6.95	25.48
10	1.47	5.39

Firdaus et al. (2010)

*Data from Total C to Total CO_2 used the factor 44/12

Table 4. Embodied carbon dioxide emission of the materials for plant construction.

Material	Embodied CO_2 emission (kg-CO_2 kg-material^{-1})
Concrete	0.16
Stainless Steel	6.15
Steel	1.37
Cast iron	1.91
Galvanized Sheet	1.45
Gravel	0.30

Hammond and Jones (2011), cited by Greenspec UK

Year 2: Operation of The Whole JME Production System

During this period, fruit yield was already sufficient and the processing plant was already operating. The Jatropha plants are assumed to live for 50 years, but the study limits the carbon footprint within a 3-year time frame. The last year serves as the estimate for the annual net CO_2e footprint. The inventory included all the activities from the farm to the processing facility and to the end-use of biodiesel.

Farm. From this year and the years onwards, it was conservatively projected that on the average, 4 Mg fresh fruits was harvested ha^{-1}, which is equivalent to 1.82 Mg dry seeds ha^{-1}. Harvesting was done manually to pick only the ripe fruits. The *Jatropha* fruits harvested were presumed to be 30% husk and 70% seed. Initially, the seeds were assumed to have a moisture content (MC) equivalent to 42% (wet basis) and 7% after sun drying. Meanwhile, husk contains 10.73% moisture (wet basis).

It was also assumed that the fruits were duhusked in the field before transferring to the processing facility. The dehusker has a fuel economy of 0.00075 L diesel kg^{-1} fresh fruit (**Table 1**). For transport, the seeds were placed in woven sacks, while husks were simply piled up the heavy-duty truck with a hauling capacity of 10 Mg and has a fuel economy equivalent to 2.126 km L^{-1}. It was estimated that the plantation is located 50 km from the biodiesel plant.

The carbon footprint of *Jatropha* seed feedstock production at the farm level was estimated from the fertilizer utilization, the materials used, and the fuel utilized for the transport of the *Jatropha* seeds and husk. Emission factors were obtained from the BioGrace GHG Calculation Tool (**Table 2**). The plants are able to sequester 71.5 Mg CO_2 ha^{-1} (**Table 3**).

Facility. In the processing plant, carbon inventory includes the total power requirement of the plant and the material inputs needed to carry out several chemical reactions to convert *Jatropha* crude oil to biodiesel.

The dried seeds from the plantation with 37% (w/w) oil, 7% MC, and 56% solids were crushed to extract the oil content. The dirty crude oil contains significant amount of solids and water and undergoes filtration and vacuum drying. It was filtered using an automatic backflush and self-cleaning filter. Filter efficiency was assumed to be 80% and the vacuum dryer operates at a 4.67 kPa absolute pressure.

The crude oil contains 88.2% (w/w) triglyceride, 3.4% free fatty acids (FFA), 1.45% phosphatides, and 6.95% unsaponifiable matter. Before conversion to biodiesel, the crude oil needed to undergo refining (degumming and neutralization) to reduce FFA in order to avoid soap formation (saponification).

Degumming removes phosphatides by adding 0.1% phosphoric acid aqueous solution (85% w/w pure) (*Hernandez and Lusa, 1996*). The dirty crude oil was degummed at 60°C for 30 min. As a result, all of the phosphatides were converted to gums; a mole of water hydrates a mole of phospholipid; any excess water does not hydrolyze the oil; and there is no excess phosphoric acid. After the reaction, the mixture was separated in a decanter centrifuge where 99.5% of the water, 99% of the gums, and 0.5% of the triglycerides were removed.

Afterwards, the degummed oil undergoes alkali refining in a tank that operates at 70 °C and 101.35 kPa that removes 99% of the free fatty acids (FFA). Sodium hydroxide aqueous solution (9.5% w/w) was added at 113% excess of the stoichiometric requirement. Soft wash water at 15% (w/w crude oil) was added to dissolve soaps and form soapstock (*Sheehan et al. 1998*). The mixture then enters a centrifuge that removes 99% soap and 99.5% NaOH. It was assumed that the water contained in the degummed oil does not hydrolyze. And then, oil was washed further of leftover soap and sodium hydroxide by spray washing with 20% water (w/w of the triglyceride content). The washed oil was vacuum dried which removes 95% of the water content. This produced refined oil with the following composition: 0.05% (w/w) water, 89.43% TAG, 0.04% FFA, 0.02% phosphatides, 10.47% others.

The refined oil was then subjected to base-catalyzed transesterification in continuous stirred tank reactors (CSTR). The refined oil stream entered the first CSTR with 85% conversion efficiency. Conversion of the refined oil to biodiesel was achieved by the addition of methanol and sodium hydroxide solution (50% solution in H_2O) at 1:6:0.20 TAG:methanol:sodium hydroxide ratio. The reaction took place at 55°C whereby biodiesel and glycerol were produced. The products were separated via a decanter in ester and glycerol streams. The ester stream, which contains methyl esters, unreacted oil, methanol, and soaps underwent further conversions, while the glycerol stream (glycerol, methanol, sodium methoxide, soaps) was drawn off to a collecting tank. The glycerol phase contains 60% of the total methanol input, all glycerol and sodium methoxide produced in the tank, and 10% of the total amount of soaps (*Van Gerpen et al. 2003*). The ester phase undergoes another transesterification using the same ratio as in the previous reaction tank, with a conversion efficiency of 96%.

The ester phase still contains impurities (methanol, soaps, and free glycerol), thus to comply with the standards set by the Philippine National Standards for commercial biodiesel, purification is necessary which was carried out in wash columns. After washing, the ester was dried using vacuum dryer operating at 4.67 kPa absolute pressure, producing methyl ester with 96.67% purity with density equal to 887.42 kg m^{-3}.

The system recovers methanol by acidulation by the addition of HCl, which produces 81.86% pure glycerol and 96.14% pure methanol. Additionally, the production plant was designed to have its own facility that co-generates power from seed husks and pressed cake, the by-products of the process. The system followed the Rankine cycle, with single reheat and two feedwater heaters with a boiler efficiency of 70% and an overall efficiency of 42.7%.

Biodiesel end-use. After production, the biodiesel produced was transported to the blending facility. It was assumed that the transportation distance from the production plant to the blending facility was 150 km. The biodiesel was transported using a heavy-duty truck with 20,000 L hauling capacity at 2.126 km L^{-1} fuel economy (*ANL 2014*). The carbon emission on the part of the end-users was computed based on the emission factors of the fuel source (**Table 5**).

For each stage, the balance of carbon emission and carbon sequestration was accounted. If there is carbon debt, it was identified if the carbon sequestered during that year will be able to instantly payback the debt. Ultimately, the net carbon footprint determines if the whole system of JME production can help sustain the environment.

A comprehensive analysis on the comparison of the production and use of biodiesel in contrast with petroleum diesel was also done after the life-cycle assessment (**Table 6**). Two analyses were conducted: same volume analysis; and same energy content analysis. Furthermore, GHG reduction using different blending scenarios were conducted.

Table 5. GHG emission factors for the overall plant operation.

Chemicals or Reagents[1]	**CO_2 emission (kg-CO_2 kg-material^{-1})**
Phosphoric acid	2776
Sodium Hydroxide	439
Methanol	1,981.44
Hydrochloric Acid	717.4
Fuels	**CO_2 emission (kg-CO_2 liter^{-1})**
Diesel[2]	3.96
Gasoline[3]	2.35
Ethanol[4]	1.51
Power Generating Feedstocks	**CO_2 emission**
Coal[5]	0.534 kg-CO2 kWh^{-1}
Biogas[6]	0.25 kg-CO2 kWh^{-1}
Pressed cake and husk[7]	392.66 kg-CO2 kWh^{-1}

[1]Biograce GHG Calculation Tool Standard Values; [2]*Mendoza* (*2014*); [3]*US EPA* (*2014*) United States Environmental Protection Agency; [4]Derived value;[5] IPCC Carbon Dioxide Intensity of Electricity – Philippines; [6]*Clark* (*2013*); [7]Derived from analysis given by *John* (*2012*)

Table 6. Emission factors for biodiesel and petroleum diesel.

Emission factors		
Fuel	MJ L^{-1} [1]	gCO_2 MJ^{-1} [2]
Biodiesel	33.22	58.08
Petroleum diesel	35.65	87.64

[1]*Appendix A Boundy et al. 2011;*
[2]*BioGrace GHG Calculation Tool, 2013*

RESULTS AND DISCUSSION

For every period, the total carbon emission and sequestration was presented (**Table 7**). The operation of the whole *Jatropha* methyl ester production considered a very conservative annual yield of 4 Mg ha^{-1} a^{-1} fresh fruit. This yield corresponds to 41,850 ha of plantation requirement so that a 30-MLPY processing plant can operate for 24 hrs d^{-1} at 300 d yr^{-1}. At the 2x2 plantation configuration, the plantation needed 104,625,000 *Jatropha* seedlings.

Year 0: Nursery Establishment and Transfer to Plantation

The year focused on the establishment of the plantation of *Jatropha*. The total carbon dioxide emission amounted to 56,951.21 Mg CO_2e for the whole year. The use of LDPE accounted for the 44% of the total emission while farming practices accounted for the other 56%. At the same time, the system can sequester 225,571.50 Mg CO_2e, leaving a negative net carbon emission amounting to 168,620.29 Mg CO_2e. Computation shows that the carbon debt incurred can already be paid off within the same year. This carbon dioxide savings may be a source of income if the organization may sell carbon credits.

Year 1: Plantation Maintenance and Construction of Facility

The plantation was maintained by pruning and weeding by labor. The nutrients of the soil are replenished by the addition of fertilizer at the same rate as in Year 0. Overall, the plantation contributes 20,527.94 Mg CO_2e during this period because of the application of fertilizer.

Construction, on the other hand, accounts for 6,666.42 Mg CO_2e. The corresponding carbon dioxide emission has a total of 6,472.68 Mg CO_2e (**Table 8**). Adding to this emission is the transport of the materials. Using the total bill of materials, the number of trips for exporting the materials to the construction area was estimated to be 3,544, which emits an equivalent carbon dioxide equal to 237.83 Mg.

The plants, during this stage, were able to sequester 1,066,477.50 Mg CO_2, which also leaves the system a negative net carbon footprint equivalent to 1,039,283.13 Mg CO_2e. This shows that the system is able to cover its carbon debt within the same year. And again, this carbon savings can be considered if one intends to do an economic study of the system.

Year 2: Operation of the Whole JME Production System

The plantation nutrients were replenished again using the same rate applied with the previous years. The processing plant requires 775.54 Mg fresh fruits for its daily operation. The fruits were handpicked and dehusked in the plantation before hauling to the processing facility. These activities contributed 35,816.79 Mg CO_2e a^{-1} to the emission. Meanwhile, processing to biodiesel emited 15,972.28 Mg CO_2e a^{-1}. Afterwards, the biodiesel delivered to the blending facility and contributes another 301.98 Mg CO_2e a^{-1}. Assuming that all the biodiesel were used up, contributed 72,780.00 Mg CO_2e a^{-1}.

The byproducts of the process are used to fire the boiler for electricity generation. Using the seedcake generates 10.17 MW power, while husks generate 14.86 MW. The combustion of these materials contributes 163,613.69 Mg CO_2e a^{-1}. The facility only uses 662.67

Table 7. Summary of Results of Biodiesel Production from *Jatropha*.

Plantation area required	41,850 ha
Number of plants required	104,625,000 units
Year 0 – Nursery and Plantation	
Sector	Emission, Mg CO_2e
Nursery	
LDPE (104,625,000 units)	25,319.25
Plantation	
Land preparation and weeding	11,104.02
Fertilizer[1]	
Urea	9,422.23
Superphosphate	1,703.89
Muriate of Potash	734.17
CO_2 soil emissions from urea application	1,534.50
N_2O soil emissions from urea application	7,133.15
TOTAL CO_2e emission	56951.21
TOTAL CO_2 sequestered	(225,571.50)
NET CO_2e emission/sequestration	(168,620.29)
Year 1 – Plantation and Facility Construction	
Plantation	
Weeding (Labor)	
Fertilizer1	
Urea	9,422.23
Superphosphate	1,703.89
Muriate of Potash	734.17
CO_2 soil emissions from urea application	1,534.50
N_2O soil emissions from urea application	7,133.15
Facility Construction*	
Section	
Structural	2,040.16
Equipment	403.08
Footing	4,031.24
Piping	1.79
Transport of Materials	237.83
TOTAL CO_2e emission	27,194.37
TOTAL CO_2 sequestered	(1,066,477.50)
NET CO_2e emission/sequestration	(1,039,283.13)
Year 2 – Operation of the Whole System	
Plantation	
Weeding (Labor)	
Fertilizer[2]	
Urea	9,422.23
Superphosphate	1,703.89
Muriate of Potash	734.17
CO_2 soil emissions from urea application	1,534.50
N_2O soil emissions from urea application	7,133.15
Harvesting (via Labor)	
Dehusker[3]	511.71
Storage (Woven PP bag)	11,567.52
Hauling (Plantation to Biodiesel Facility)	3,209.62
Facility Operation	
Transesterification*	
Phosphoric Acid	80.50
Sodium Hydroxide	234.55
Methanol	15481.91
Hydrochloric Acid	175.31
Cogeneration*	
Seedcake for combustion for power generation (10.17 MW)	74,902.93
Jatropha husk for combustion for power generation (14.20 MW)	84,630.28
Electricity consumption (662.67 kW, assumed all from husk)	4,080.48
Transportation of biodiesel to blending facility*	301.98
Biodiesel end-use	72,780.00
TOTAL CO_2e emission	288,484.74
TOTAL CO_2 sequestered	(1,994,850.00)
NET CO_2e emission/sequestration	(1,706,365.26)

Table 8. The amount of construction materials used for the facility and the corresponding carbon dioxide emission.

Structure	Material, Mg					Mg CO$_2$e emission
	Galvanized Sheet	Steel	Concrete	Stainless Steel	Gravel	
Structural	26.91	1,208.56	387.65	46.08		2,040.16
Equipment		294.22				403.08
Footing		601.50	10,374.53	23.03	4685.36	4,031.24
Piping		1.30				1.79
TOTAL	26.91	2,105.59	10,762.17	69.11	4685.36	2,040.16
TOTAL Mg CO$_2$e	39.02	2884.65	1721.95	425.04	1405.61	6,472.68

kW (corresponding to 4,080.48 Mg CO$_2$e a^{-1} emission, based on the intensity of burning the *Jatropha* husk) and the remaining can be sold to the grid and generate opportunity savings of carbon dioxide. The total emission of the system amounts to 288,484.74 Mg CO$_2$e a^{-1}, but again, the plants were able to sequester carbon dioxide which amounts to 1,994,850.00 Mg CO$_2$e a^{-1}. The whole system then became carbon-negative with a net CO$_2$e footprint of -1,706,365.26 Mg CO$_2$e a^{-1} (**Table 9**).

The data were used to compare the GHG emission of biodiesel with petroleum diesel fuel. The whole system of biodiesel production was compared with petroleum diesel, considering the GHG savings generated. Two analyses were conducted: same volume analysis; and same energy content analysis.

Same Volume Basis. The analysis was based on the 30-ML biodiesel volume. The analysis considered the life-cycle of biodiesel production with cogeneration compared to the life cycle of petroleum diesel fuel and the equivalent electricity considering the Philippine energy mix carbon intensity. In comparison, biodiesel production released 40.07% less GHG than petroleum diesel (**Table 10**). During end-use, biodiesel was 14.97% cleaner in terms of GHG emission. Adding to this savings was the opportunity savings acquired from utilizing the byproducts to produce electricity. The excess power that could be sold to the grid can replace the load that would have been generated at a higher carbon intensity of the Philippine energy mix, and creates 25.27% cleaner energy. Furthermore, the renewable energy system sequesters carbon dioxide whereas energy from fossil fuels does not. Overall, comparing the two systems, biodiesel facility with cogeneration is 534.24% better than the life-cycle of petroleum diesel fuel and the fossil fuel-generated electricity. Even without sequestration, the biodiesel system effects a 26.55% reduction in GHG emission compared to petroleum diesel fuel (**Figure 2**).

Table 9. Total carbon emission for the yearly operational analysis.

Component	**Mg CO$_2$ eq a^{-1}**
Production	
Plantation	32,607.17
Transportation (plantation to biodiesel plant)	3,209.62
Plant Operation	15,972.28
Cogeneration Facility (Electricity for Plant Operations)	4,080.48
Transportation (Biodiesel plant to blending facility)	301.98
Subtotal	**56,171.53**
Cogeneration CO$_2$ emissions (husk + seedcake)	159,533.20
Biodiesel *End-Use* emissions	72,780.00
Subtotal	**232,313.20**
Total CO$_2$e emission	**288,484.74**
Less: Carbon Sequestration	**(1,994,850.00)**
NET TOTAL	**(1,706,365.26)**

However, comparison based on same volume is a questionable result because the energy content of one liter biodiesel is lower than one liter petroleum diesel. Thus, a direct volume replacement was not technically equivalent. Obviously, to justify the capability of biodiesel to replace petroleum diesel, it should be able to supply the equivalent energy content and not just the volume. It may be argued that because biodiesel contains less energy than diesel, more volume is needed to provide the same energy, thereby will “emit more carbon dioxide” in the long run. Biodiesel contains 33.22 MJ while petroleum diesel contains 35.65 MJ per liter, thus, the energy content of one liter petroleum diesel equal to 1.07 L biodiesel. The analysis based on the same energy content (**Table 11**) shows the results were almost the same but an even slightly higher GHG emission reduction than with the same volume analysis. The whole biodiesel system with cogeneration, considering the sequestration capability of the plants, is 548.38% better than the PDF system. Even without considering the sequestered carbon dioxide, the biodiesel system still emits 24.20% less GHG (**Figure 3**).

In both analyses, the use of biodiesel greatly imposes carbon savings wherein emissions from the build-up phase were immediately recovered. Also, the electricity from the byproducts of biodiesel production emits less carbon dioxide than the rated emission for the Philippine electricity.

Table 10. Comparison of JME and petroleum diesel on a same volume assessment.

Same volume basis (30MLPY)			
	Biodiesel + Electricity Cogeneration	**Petroleum diesel + Electricity**	**GHG Reduction**
	(Mg CO_2e a^{-1})		
Fuel Production	56,171.53	93,730.98	40.07%
Electricity	159,533.20	213,466.33	25.27%
Fuel End-use	72,780.00	85,590.00	14.97%
Sequestration	-1,994,850.00		
Total	**-1,706,365.26**	**392,787.31**	**534.42%**
TOTAL SAVINGS	**-2,099,152.57 Mg CO_2e a^{-1}**		

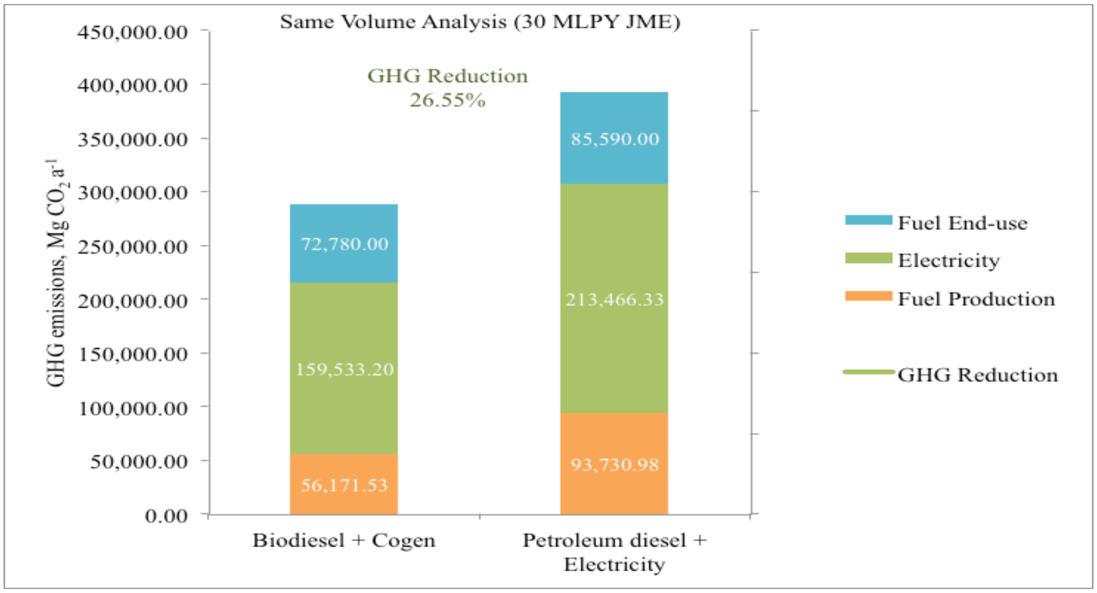

Figure 2. Total GHG reduction from JME compared to petroleum diesel, without sequestration (same volume).

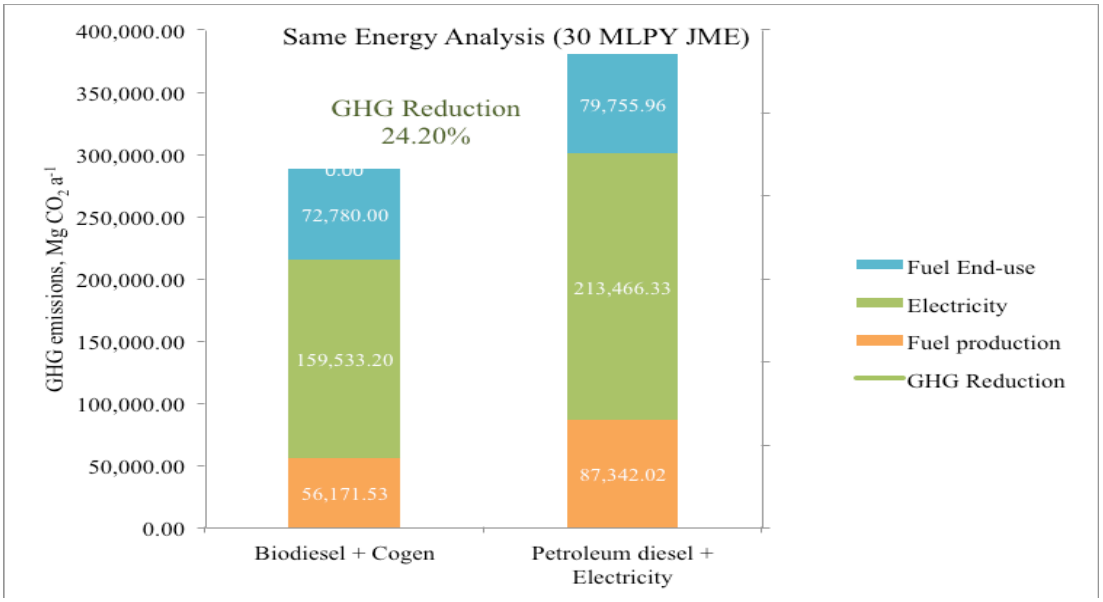

Figure 3. Total GHG reduction from JME compared to petroleum diesel, without sequestration (same energy).

The use of these materials as fuel for boiler is preferred because these materials contain toxins, which could expose humans and animals to chronic and acute conditions (*US FDA 2014*). Thus, harnessing its energy content is a better option because aside from its relatively lower emission than with Philippine electricity, it is renewable and additional

Table 11. Comparison of JME and petroleum diesel on a same energy assessment.

Same energy basis (30MLPY)			
	Biodiesel + Electricity Cogeneration	**Petroleum diesel + Electricity**	**GHG Reduction**
	(Mg CO_2e a^{-1})		
Fuel Production	56,171.53	87,342.02	35.69%
Electricity	159,533.20	213,466.33	25.27%
Fuel End-use	72,780.00	79,755.96	8.75%
Sequestration	-1,994,850.00		
Total	**-1,706,365.26**	**380,564.31**	**548.38%**
TOTAL SAVINGS	**2,086,929.57 Mg CO_2e a^{-1}**		

emission from having a cogeneration facility is appropriate in the industry.

The GHG savings were claculated considering the blending scenarios. **Figure 4** (same volume basis) and **Figure 5** (same energy basis) present the GHG emission savings for the different blending scenarios. The basis of both quantities was a petroleum diesel supply of 300 MLPY biodiesel volume. With the current Philippine biodiesel blending, which is at 2%, the use of JME can reduce emission by 11%. This is equivalent to GHG savings amounting to about 420,000 Mg CO_2e a^{-1} for every 300 ML blended fuel consumed (same for both basis). As the blending increases, a more positive amount of savings will be achieved, which if at B100, savings could go as high as 581%. It can be realized that using JME, if the Philippines increased blending to up to 5%, a 16% increase in savings (26.72% total) will be achieved or a total of about 1,049,576.28 mg CO_2e will be saved annually.

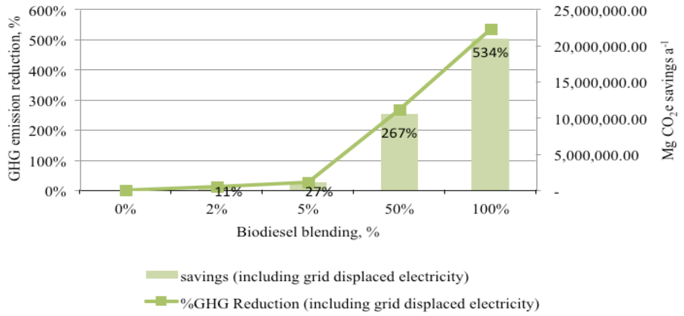

Figure 4. GHG savings from the different blending scenarios (same volume).

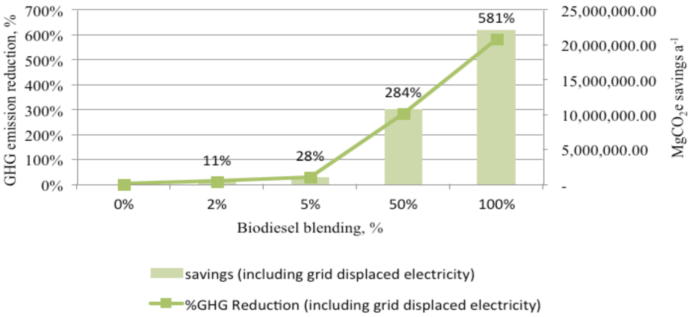

Figure 5. GHG savings from the different blending scenarios (same energy).

CONCLUSION AND RECOMMENDATIONS

The carbon inventory of a commercial-scale *Jatropha* biodiesel plant assessed in the study showed that the overall system is carbon-negative. The life-cycle carbon footprint of *Jatropha* biodiesel is about 25% better in terms of GHGemission compared to petroleum diesel fuel. Furthermore, considering the sequestration capability of the plants, the system becomes even more commendable because it can reduce GHG emission by about 540%.

Comparing the work with *Eshton et al.* (*2013*), who also conducted LCA of *Jatropha* methyl ester from cradle-to-grave utilizing local data from Tanzania, the *Jatropha* methyl ester production system designed in this study, without considering the sequestration capability of the *Jatropha* plants, emits three times more CO_2e Mg^{-1} biodiesel (10,804 compared to 3,608 kg CO_2e Mg^{-1} biodiesel). However, due to the difference in the amount of carbon dioxide absorbed in the farm, the net GHG emissions derived were conflicting. *Eshton et al.* (*2013*) derived the sequestration capability of the *Jatropha* plants by converting the carbon content of a plant to a per hectare basis with their planting density assumption of 1,250 ha^{-1}, hence garnering a smaller factor for *Jatropha* sequestration per area. The research study used the empirical data from Malaysia for the sequestration capability of *Jatropha*, hence standing firm with the result that the whole JME production system from cradle-to-grave is carbon negative, within the specified system boundary.

Energy-wise, studies made by *Eshton et al.* (*2013*), and *Prueksakron and Gheewala* (*2008*) proved that there is net energy gain in using *Jatropha* biodiesel compared to petroleum diesel. Further studies on the water footprint and economic viability of the project is as vital, hence, the authors recommend conducting supplementary studies to cover all the aspects for the sustainability of *Jatropha* biodiesel production and commercial use.

This study designed a hypothetical scenario of *Jatropha* biodiesel production; variables such as land area needed and distances were presumed. Thus, if the data will be used for local inventory, adjustments may be projected by considering the values assumed in this study. Also, simplification for the agronomic side was used in this study, which might not be acceptable experts in the field. The values were disaggregated for future use and reference the data to add other sources that were not considered and make their own computation depending on the need and circumstances.

REFERENCES

[AFDC, US DOE] Alternative Fuels Data Center, US Department of Energy. 2016. Biodiesel Blends. Accessed from http://www.afdc.energy.gov/fuels/biodiesel_blends.html

[ANL] Argonne National Laboratory. 2014.Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation 2013. U.S. Department of Energy. Accessed September 2014 from https://greet.es.anl.gov/

[CCC] Climate Change Commission. 2016. National Climate Change Policy and the Potential Role of Market-Based Mechanisms in the Philippines. 14th Partnership Assembly of the Partnership for Market Readiness Conference, 26 April 2016. Accessed June 2017 from https://www.thepmr.org/system/files/documents/Philippines%20National%20Climate%20Change%20Policy%20and%20the%20Potential%20Role%20of%20Market%20Based%20Mechanisms%20%28April%202016%29.pdf

[IRENA & ACE] International Renewable Energy Agency & ASEAN Centre for Energy. 2016. Renewable Energy Outlook for ASEAN: a REmap Analysis. International Renewable Energy Agency (IRENA), Abu Dhabi and ASEAN Centre for Energy (ACE), Jakarta. Accessed June 2017 from http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_ASEAN_2016_report.pdf

[ISAAA] International Service for the Acquisition of Agri-biotech Applications. 2014. Philippines Boosts Biodiesel Production. Accessed October 30, 2014 from http://www.isaaa.org/kc/cropbiotechupdate/article/default.asp?ID=11900

[PEP 2012-2030] Philippine Energy Plan 2012-2030. Philippine Department of Energy. Accessed June 2017 from https://www.doe.gov.ph/sites/default/files/pdf/pep/2012-2030_pep.pdf

[SECO] Senate Economic Planning Office. 2014. Renewable Energy at a Glance. Accessed from https://www.senate.gov.ph/publications/AAG%20on%20Renewable%20 Energy_June%2030_FINAL.pdf

[US EPA] US Environmental Protection Agency. 2014. Greenhouse Gas Emissions From a Typical Passenger Vehicle. Office of Transportation and Air Quality Office. EPA-420-F-14-040a. Accessed September 2015 from https://www.epa.gov/sites/production/files/2016-02/documents/420f14040a.pdf

[US FDA] U.S. Food and Drug Administration. 2014. FDA Notification to Industry: Products using Oils, Glycerin, or Protein that were Derived from the *Jatropha* Plant May have Toxic Effects. Accessed November 10, 2014 from http://www.fda.gov/ForIndustry/IndustryNoticesandGuidanceDocuments/ucm391133.htm

Beaver, A., Castaño, A.G. and M.S. Diaz. 2016. "Life Cycle Analysis of *Jatropha curcas* as a Sustainable Biodiesel Feedstock in Argentina". Chemical Engineering Transactions, 50: ISBN 978-88-95608-41-9; ISSN 2283-9216. *The Italian Association of Chemical Engineering* Online doi: 10.3303/CET1650073 Biograce GHG Calculation Tool. 2013. Accessed from http://www.biograce.net/content/ghgcalculationtools/overview

Biograce GHG Calculation Tool. 2013. Accessed from http://www.biograce.net/content/ghgcalculationtools/overview.

Boonkum, P., Mungkalasiri, J., Thanungkano, W., Nohtomi, M., Nagata, K. and H. Onoda. n.d.. The Impact of Different Farm Management Ssystems on *Jatropha* Cultivation for Biodiesel Feedstock: A Case Study in Thailand. Accessed September 25, 2014 from http://conference.alcas.asn.au/alcasprogram/Pornpimon_Boonkum_ Reviewed_paper.pdf

Boundy, B., Diegel, S.W., Wright, L., and S.C. Davis. 2011. Biomass Energy Data Book. 4th ed. Accessed from http://cta.ornl.gov/bedb/pdf/BEDB4_Full_Doc.pdf

Clark, D. 2013. Information Paper-4 CO_2e Emissions from Biomass and Biofuels. Cundall Johnston & Partners LLP. Accessed September 2015 from http://www.cundall.com/Cundall/fckeditor/editor/images/UserFilesUpload/file/WCIYB/IP-4%20-%20CO2e%20emissions%20from%20biomass%20and%20biofuels.pdf

Corpuz, P. (2013). Philippines Biofuels - Annual Philippine Biofuels Situation and Outlook. USDA Foreign Agricultural Service Global Agricultural Information Network. Accessed September 2014 from https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Manila_ Philippines_7-10-2013.pdf

de Lima, R.dL.S., Campos, A.R.F., de Azevedo, C.A.V., Calado, J.A.W., Silva, S.dS. and R. do Nascimento. 2016. "Effectsof Planting Density on Vegetative Growth and Production Components of *Jatropha* (*Physic nut* L)". *Australian Journal of Crop Science* 10(5):632-636 (2016) doi: 10.21475/ajcs.2016.10.05.p7148. Accessed from http://www.cropj.com/lima_10_5_2016_632_636.pdf

Diédhiou, I., Diallo, D., Mbengue, A.A., Hernandez, R.R., Bayala, R., Diémé, R., Diédhiou, P.M., and Sène, A. 2017.

"Allometric Equations and Carbon Stocks In Tree Biomass of Jatropha curcas L. in Senegal's Peanut Basin." Elsevier Global Ecology and Conservation. Vol 9, pp 61-69. Accessed June 2017 from http://www.sciencedirect.com/science/article/pii/S2351989416301081

Eshton, B., Katima, J.H.Y., and Kituyi, E. 2013. "Greenhouse Gas Emissions and Energy Balances of Jatropha Biodiesel as an Alternative Fuel in Tanzania." *Biomass and Bioenergy* Vol 58, pp. 95–103. Accessed September 2015 from http://www.sciencedirect.com/science/article/pii/S0961953413003668

FACT Foundation. 2010. The *Jatropha* Handbook from Cultivation to Application. The Netherlands Horsten 1 5612 AX Eindhoven. ISBN 978□90□815219□1□8

Firdaus, M.S., Hanif, A.H.M., Safiee, A.S. and M.R. Ismail. 2010. Carbon Sequestration Potential in Soil and Biomass of *Jatropha curcas*. Paper presented on the 19th World Congress of Soil Science, Soil Solutions for a Changing World in Brisbane, Australia, 1-6 August 2010. Accessed from http://iuss.org/19th%20WCSS/Symposium/pdf/0423.pdf

Hammond, G. and C. Jones. 2011. "Embodied Energy". Greenspec. Accessed from http://www.greenspec.co.uk/embodied-energy.php.

Hernandez, E., and Lusas, E. W. 1996. Practical Short Course in Processing of Vegetable Oils. College Station, Texas, USA: The Texas AandM University System. Accessed from http://www.jatropha.pro/nursery.htm.John, G.R. (2012). A study on the feasibility of *Jatropha* husks and *Jatropha* cake as gasifier feedstocks. *International Journal of Innovative Research and Development*, Vol 1 Issue 7. Retrieved October 27, 2014 from the world wide web: www.ijird.com.

Jatropha Organisation of South Africa. 2008. Jatropha Seed Benchmarks, Germination & Planting Instructions. Accessed September 2014 from http://www.jatropha.org.za/Jatropha%20Seed%20Benchmarks,%20Germination%20&%20Planting%20Instruc.pdf

Mendoza, T.C. 2014. "Reducing the Carbon Footprint of Sugar Production in the Philippines." *International Journal of Agricultural Technology* 2014 Vol. 10(1): 289-308. ISSN 1686-9141. Accessed September 2015 from http://www.ijat-aatsea.com/pdf/v10_n1_14_January/26_IJAT_2014_10(1)__Teodoro%20Mendoza-Plant%20Science.pdf

Prueksakorn, K., and S.H. Gheewala. 2013. "Full Chain EnergyAnalysis of Biodiesel from *Jatropha curcas* L. in Thailand". *Environmental Science and Technology.* ACS Publications. Accessed from http://pubs.acs.org/doi/pdf/10.1021/es7022237

Rao, Y.V.H., Voleti, R.S., Hariharan, V.S., Raju, A.V.S., and P.N. Redd. 2009. "Use of *Jatropha* Oil Methyl Ester and Its Blends as an Alternative Fuel in Diesel Engine". *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, http://dx.doi.org/10.1590/S1678-58782009000300011. ISSN 1806-3691. Accessed from http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1678-58782009000300011

Sheehan, J., Cambreco, V., Duffield, J., Garboski, M., and H. Shapouri .1998. An Overview of Biodiesel and Petroleum Diesel Life Cycles. Report. US Department of Agriculture and Energy. pp: 1–35.

Symphony Environmental. 2011. A Carbon Footprint Analysis of Plastic bags: A Review of the Life Cycle Analysis on Carrier Bags. UK Environment Agency. Accessed September 8, 2014 from http://www.d2wusa.com/files/CarbonFootPrintof PlasticBags.pdf.

The Jatropha Organisation of South Africa. 2008. Jatropha Seed Benchmarks, Germination & Planting Instructions. Accessed September 2014 from http://www.jatropha.org.za/Jatropha%20Seed%20Benchmarks,%20Germination%20&%20Planting%20Instruc.pdf

Uriarte Jr., F.A., and A.B. Culaba. 2008. "Getting Real with *Jatropha*". Proceedings of the NAST Roundtable Discussion and Workshop on Biofuels: Focus on *Jatropha*. Accessed October 30, 2014 from http://www.nast.ph/index.php/downloads/ category/12-nast-monograph?download=50:series-15-getting-real-with-jathropa

Van Gerpen, J., D. Clemens, G. Knothe, B. Shanks, and R. Pruszko. 2003. Biodiesel Production Technology. Biodiesel Workshop. Ames, Iowa.: Iowa State University.

Villancio, V.T., Demafelis, R.B., de Ramos, J.D., Limosinero, R.L., Villavicencio, M.L.H., Icao, F.R.C., Baradas, F.C., and M.K.P. Irader. 2012. *Jatropha* Production and Processing Manual. Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD). Department of Science and Technology. Book Series No. 01/2012.

Von Maltitz, G., Gasparatos, A., and C. Fabricius. 2014. "The Rise, Fall and Potential Resilience Benefits of *Jatropha* in Southern Africa". *Sustainability*. 6: 3615-3643; doi:10.3390/su6063615. ISSN 2071-1050. Accessed November 4, 2014 from the world wide web: www.mdpi.com/journal/sustainability

Wani, S., Chander, G., Sahrawat, K. Ch, S., Raghvendra, G., Susanna, P. & Pavani, M. 2012. "Carbon Sequestration and Land Rehabilitation Through Jatropha curcas (L.) Plantation in Degraded Lands." Agriculture, Ecosystems & Environment. 161. 112–120. 10.1016/j.agee.2012.07.028. Accessed June 2017 from https://www.researchgate.net/publication/257015754_Carbon_sequestration_and_land_rehabilitation_through_Jatropha_curcas_L_plantation_in_degraded_lands