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Life Cycle Assessment of the Oil Palm Production in the Philippines: A Cradle to Gate Approach

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ABSTRACT

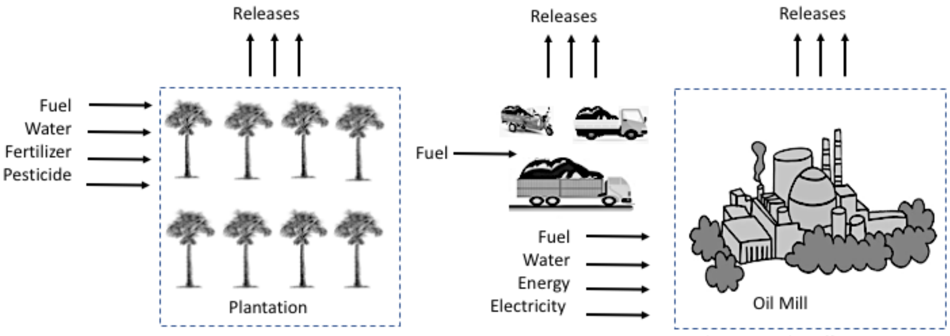
Despite its small share of 0.15% in the global market, the oil palm production in the Philippines is being contested with environmental issues on continued deforestation, increased emissions from illegal burning of trees, and the marginalization of indigenous communities. As a developing industry, there is a need to further conduct of social and environmental impact studies to gain more acceptance, thereby, pursue growth and expansion. In view of the environmental concerns, this study aimed to conduct a life cycle assessment of the crude oil palm with North Cotabato, Philippines as the case study. Using cradle to gate approach, the potential environmental impacts were established: non-renewable energy of 0.394 MJ/kg oil, carbon footprint of 1.150 kgCO_2/kg oil, ozone creation potential of 2.429×10^{-3} kg NOx /kg oil, acidification potential of 0.0138×10^{-3} kg SO_2 /kg oil and water footprint of 5,797.3 L/kg oil. Compared to six locations in Indonesia, Malaysia and Thailand, the environmental impacts and performance of the oil palm production in North Cotabato were satisfactory given the same topographical conditions. Opportunities to mitigate and decrease the impacts were also identified, namely improving oil extraction rates; increasing ratio of shell as biomass fuel; prudent application of nitrogen fertilizers and optimizing delivery loads and schedules. The results of this study can be a reference for future environmental assessments in other locations.

INTRODUCTION

The oil palm production in the Philippines (0.15%) can be considered as a developing industry relative to its neighbouring countries, which are the top three oil palm producers namely: Indonesia (55%), Malaysia (29%), and Thailand (4%) in the world market of 69.77 million MT as of 2017 (Index Mundi 2018). It started as early as 1950 in Basilan Province. However, the growth was insignificant in its first decade. In the mid of 1960s, it was more felt with the conversion of ramie plantation to oil palm by Kenram in Sultan Kudarat and supported by their own oil mill. There was a significant growth starting 2000 onwards as more private companies operated in Agusan del Sur and Maguindanao provinces (PRDP 2014).

As of 2016, there were 60,069 hectares planted with oil palm, growing at average of 4.4% per annum. The farms are primarily found in Mindanao with Soccsksargen and Caraga regions as key drivers of the industry, as given in Table 1. In terms of production, the highest recorded production was in 2010 with 565459.5 tons of fresh fruit bunches (FFB). It declined in 2016 with only 439528.6 tons (CountrySTAT Philippines 2018). It is still recovering after the extensive damages of plantations in Davao and Caraga regions due to Typhoon Pablo, which affected most of the agricultural crops (PRDP 2014).

Indeed, the oil palm has a very huge potential in the vegetable oil industry because of its numerous advantages versus other crops, namely: yield; planting and maintenance; simple post-harvest handling; suitability on idle grassland, bushlands and logged over secondary forests (Batugal 2013). Collectively, oil palm can be seen as the least expensive vegetable oil to produce, given that its output of 3.8 ton oil/ha as compared to soybean (0.5 ton oil/ha), sunflower (0.7 ton oil/ha) and rapeseed (0.8 ton oil/ha) (European Palm Oil Alliance 2018). Furthermore, the oil palm produces two types of oils, palm oil and palm kernel oil. They are not limited to the cooking oil function since they have various applications in other industries such as personal care, household care, cosmetics, animal feeds and



Photos Source: https://png.pngtree.com

Fig. 1: Cradle to gate system boundary of oil palm production.

Table 1: 2016 inventory of oil palm plantation and fresh fruit bunches.

National/ Regional/ Province	Area in HAS	% Share	FFBS in Tons	% Share
Philippines	60,069.00	100.00	439,528.60	100.00
Luzon	5,900.00	9.82	19,426.80	4.42
Visayas	6,500.00	10.82	25,468.50	5.79
Mindanao	47,669.00	79.36	394,633.30	89.79
Zamboanga-peninsula	4,568.00	7.60	3,012.80	0.69
Northern Mindanao	4,340.00	7.23	42,397.00	9.65
Davao Region	1,069.00	1.78	4,129.90	0.94
Soccsksargen	17,845.00	29.71	153,175.00	34.85
Caraga	17,397.00	28.96	168,817.60	38.41
Armm	2,450.00	4.08	23,101.00	5.26

biodiesel. Practically, most of the oil palm tree parts are being maximized since agricultural by-products are being used as fertilizers while processing by-products as biomass fuel. Other parts can still be explored for value addition to become fibre board, paper and the like (PRDP 2014).

In spite of the great potential in oil palm, some groups are still worried on its detrimental effects, which include continued deforestation, increased emissions from illegal burning of trees, and the marginalization of indigenous communities. It was assured that unlike in Indonesia and Malaysia where rainforests were destroyed in favour of oil palm plantations, those in the Philippines were cultivated in logged-over areas. The environmental allegations were countered with scientific evidence and findings to disprove the negative effects of the oil palm trees and oil palm farming. It was also highlighted that there were biases towards other crops like soybean, corn, rapeseed and canola for them to have a bigger share in the expanding vegetable oil market in the country. It was then recommended that the expansion of oil palm be carried out to meet the increasing domestic shortage of vegetable oil for steady supply and food security (Pamplona 2013). In a separate report, it was recommended that the oil palm to be seen as a "big brother" of the coconut industry rather than as a threat. It has been proven that they were complementing each other in terms of exports, pest management, production yields and poverty alleviation initiatives (Pamplona 2017).

In 2014, the experts of the Roundtable on Sustainable Palm Oil (RSPO), agreed and made recommendations for increasing productivity, improving livelihoods and reducing environmental impacts of palm oil in the Philippines (Reyes 2014). They were summarized in five key points, namely: conduct social and environmental impact studies first; implement sustainable palm oil practices; work on a pro-farmer model; make good seeds as public goods, and create financial innovation.

In order to increase the acceptance and facilitate potential expansion, this study facilitated a life cycle assessment with the following key objectives:

- Conduct a life cycle assessment of the crude oil palm production in the Philippines.
- Establish the potential environmental impacts based on indicators and categories.
- Evaluate the environmental impacts relative to other production locations.
- Identify opportunities to mitigate or decrease the environmental impacts.

MATERIALS AND METHODS

Life Cycle Assessment (LCA)

This study utilized the Life Cycle Assessment (LCA), an environmental management tool to evaluate a certain product or process in view of assessing and optimizing the quality of a system, in terms of environmental impacts over its entire life cycle. The concept was introduced by SETAC (Society of Environmental Toxicology and Chemistry) and has become a credible technique in many sustainability and environmental assessment endeavours among policy makers, manufacturers and consumers in planning and decision making activities (Jensen 2008).

Impact Categories

There were five relevant indicators applied in this study. The first four were based on TRACI 2.1 (Tool for the Reduction and Assessment of Chemical and other Environmental Impacts), namely: energy use, climate change, acidification, ozone creation (Bare 2012) and the fifth one was water consumption based on Water Footprint Network (Hoekstraet et al. 2011). Their respective impact categories and unit of measures are as follows:

Energy use**:** Non-renewable energy (MJ), amount of primary energy extracted from the earth;

Climate change**:** Global warming potential (kgCO_2/equivalent), emissions of greenhouse gases;

Acidification**:** Acidification potential (gSO_2/equivalent), emissions which increase acidity of the environment due to various chemical reactions and/or biological activity;

Ozone creation**:** Ozone creation potential (gNOx/equivalent), emissions which cause depletion of stratospheric ozone level;

Water consumption**:** Water footprint (L/equivalent), volume of freshwater used to produce the product, measured across the supply chain.

Data Collection

The data on the material and energy flows were covered based on the various inputs and outputs within the scope of study of the two systems. The relevant data were collected from interviews of key persons from the Palm Council, Kilambay Nursery Farms and Univanich Oil Mill, company reports, industry data and related literature.

The collected data were then classified and established based on their equivalence per category. For the impacts on energy use and emissions, database on energy content, carbon emissions, specific gravity and the like for diesel and gasoline fuels were based from the Engineering Tool Box (2018). While for the biomass fuels with various mix ratios, they were derived and estimated accordingly based on prior studies (Fauzianto 2014, Moller 2012, Yap et al. 2012). For water consumption, the amount of rainwater to cover the equivalent number of hectares were estimated from the average rainfall per location based on the records of World Weather (2018).

Scope and Limitations

This study only covered one location for the Philippines since there was difficulty in getting approvals for other sites. Nonetheless, the chosen area in Carmen, North Cotabato has an integrated system from agriculture to crude oil palm production, which can also serve as a baseline since no LCA study for oil palm in the Philippines was done at this point. For agriculture, the inventory starts from the soil preparation for planting materials. The nursery operations were not included since much of the activities are in the plantation operations. On the other hand, for production, only the extracted crude oil palm is considered as finished goods for this location since refining process of oil palm is being done in other areas, some of which are being exported to other countries. Therefore, transportation and activities of the finished goods outside the oil mill premises were no longer included.

For comparative performance analysis, journals and thesis materials were gathered among six identified locations. Some of these related literature covered the biodiesel production, hence, only the data relevant up to the crude oil palm production were used for this study.

CASE STUDY: NORTH COTABATO, PHILIPPINES

The crude oil palm production basically requires FFBs, which are harvested from oil palm plantations. The life cycle analysis for North Cotabato, Philippines followed the Cradle to Gate Approach with the system boundary shown in Fig. 1. It is divided into two sub-systems: agriculture in plantation and production in oil mills.

For the life cycle inventory, materials and energy across plantation and production were quantified based on an output of 1 ton of crude oil palm for simpler profiling and comparison. On the other hand, the functional unit in measuring the environmental impacts will be based on the equivalent of 1 kg of crude oil palm.

Plantation

The aggregate of oil palm plantations being served by the oil mill in the North Cotabato system is equivalent to 5,562 hectares as of 2017. This comprised 7 clusters across North Cotabato, Sultan Kudarat, Lanao del Sur, Bukidnon and Davao del Norte.

The recommended density per hectare is 143 trees, planted at 9 m by 9 m distance. The trees have a projected lifetime of 30 years. Normally, the trees are productive with FFBs ready for harvest starting the second year. Hence, intercropping can be done with other crops within the first two years of planting, as an alternative source of income, especially among small farmers. Versus other crops, oil palm has lower maintenance since no need for much weeding and fertilization. Moreover, the removed leaves and trunks can

Table 2: Load per delivery, fuel per ton per type of vehicle.

Type of Vehicles	Load in Ton	Liter (s) per Ton
Kubota	1.20	10.00
Multi Cab (Gas)	1.50	6.23
Bongo	3.00	2.38
Jeep	3.00	3.05
Elf	6.00	1.46
Forward	12.00	0.77
10 wheeler	24.00	0.51

be used as natural fertilizers. The typical amount of fertilizers used is 12-18 50 kg-bags per hectare per year. This is an equivalent of 600-900 kilograms, which is comprised primarily of nitrogen (N), phosphorus (P), and potassium (K). They are supplemented with calcium (Ca) and boron (B) during the second year and onwards depending on the soil deficiencies.

The red orange colour in FFBs indicates that they are ready for harvest and can be taken from the palm tree. Harvesting of these FFBs can be done every 15 days by human labour, at an average of 18-25 kilos per bunch. The harvested FFBs are then transported to the oil mill, using different type of vehicles relative to farm size and distance. Considering distance, frequency and load per delivery, the equivalent fuel per delivery of 1 ton of FFBs per type of vehicle are summarized in Table 2.

There are many small farm holders as a result of the government-initiated project of giving free seedlings for 2 hectares per household, which was positioned as an alternative to hit the poverty threshold. As a result, there are many small nearby farms with deliveries done in small batches with higher fuel usage.

Oil Mill

Upon arrival at the oil mill, the FFBs are subjected to the following processes, namely: sterilization, stripping, threshing, pressing, clarification and storage. There are 2 shifts or an equivalent 20 production hours per day.

The oil mill has its own power plant sourced from the boiler, which is fuelled by biomass of 90% dry fibre and 10% shell. The dry fibre fuel (12%) and shell (6%) are by-products of FFBs. The amount of biomass fuel used is 3.6 tons of biomass fuel per hour of boiler start-up and production. Generally, the plant is self-sufficient in power generation. However, there are available firewood to be used during extreme cases when fibre and shell are inadequate. Also, the company has a stand-by generator to support production and office activities during boiler downtime.

For water consumption, it uses 20 m^3 per production hour: 17 m^3 for boiler operations and 3 m^3 for other operations and activities. It is sourced from a 10 feet-deep water pond, which facilitates rainwater collection and storage. There are 30 tons of FFBs processed per hour. With an oil extraction rate (OER) of 20%, 6 tons of crude oil palm is being processed per hour or an equivalent of 120 tons per day at the given production set-up.

RESULTS AND DISCUSSION

Life Cycle Analysis of Oil Palm Production in North Cotabato, Philippines

The respective impacts were generated from the tabulated inventory of inputs, in both plantation and oil mill operations, required to produce 1 ton of palm crude oil in Tables 3 and 4.

The accounted non-renewable energy is 0.394 MJ/kg oil. It is primarily comprised of 95.8% diesel and 4.2% gasoline. Diesel and gasoline, are for the vehicles as shown in Table 2, which are used for the delivery of FFBs to oil mill, at an average of 2 trips per month. Practically, all vehicles use diesel except for Multicab, which uses gasoline. Within the plantation, no significant use of diesel and gasoline was recorded since transportation and other movements are done mostly with animals such as carabaos.

The established carbon footprint equivalent is 1.150 kgCO_2/kg oil. It is generated from biomass at 66.3%, 31.1% from nitrogen in fertilizers, 2.5% diesel and 0.1% gasoline. The biomass is composed of the dry fibre from the pericarp of

Table 3: LCA inventory of inputs in North Cotabato, Phils.

Inputs	Unit	Amount
AGRICULTURE		
Fresh Fruit Bunches	kg	5,000.000
Nitrogen (N) from Fertilizer	kg	69.420
Phosphate (P) from Fertilizer	kg	35.863
Potassium (K) from Fertilizer	kg	35.080
Water Consumption (Rainfed)	L	5,793,750.000
Diesel Delivery Consumption to Mill	L	10.670
Gasoline Delivery Consumption to Mill	L	0.498
OIL MILL		
Oil Extraction Rate	%	20.000
Energy Consumption		
Grid	kWH	-
Diesel	L	-
Gasoline	L	-
Mesocarp Fiber	kg	567.000
Shell	Kg	63.000
Water Consumption		
Green	L	3,500.000
Blue	L	-
Gray	L	-

Table 4: Impacts per category for North Cotabato, Phils.

Impact	Unit	Amount
NON-RENEWABLE ENERGY		
Diesel	MJ	377.0965
Gasoline	MJ	16.5945
Total	MJ	393.6910
Non-Renewable Energy per kg of oil	MJ/kg Oil	0.3937
CARBON FOOTPRINTS		
Diesel	kg CO_2	28.4065
Gasoline	kg CO_2	1.1801
Biomass	kg CO_2	763.1546
Fertilizer, N	kg CO_2	357.5128
Total	kg CO_2	1,150.2539
Carbon Emission per kg of oil	kgCO_2/kg Oil	1.1503
OZONE CREATION		
Diesel	kg NOx	0.2663
Gasoline	kg NOx	0.0111
Biomass	kg NOx	2.1517
Total	kg NOx	2.4290
Ozone Creation per kg of oil	kg NOx/kg Oil $\times 10^{-3}$	2.4290
ACIDIFCATION		
Diesel	kg SO_2	0.0031
Gasoline	kg SO_2	0.0001
Biomass	kg SO_2	0.0106
Total	kg SO_2	0.0138
Acidification per kg of oil	kg SO_2/kg Oil $\times 10^{-3}$	0.0138
WATER FOOTPRINT		
Green-Agriculture	L	5,793,750.0000
Green-Production	L	3,500.0000
Blue-Production	L	-
Total	L	5,797,250.0000
Water Footprint per kg of oil	L/kg Oil	5,797.2500

fresh fruit bunches and the shell from the nuts. Currently, the company uses biomass with 90:10 fibre and shell ratio. The biomass is used to fuel the whole plant for 1 hour start-up and 20 hours processing time, at the amount of 30 tons of biomass per hour. Aside from biomass, the use of fertilizers in the plantation has a great impact on the carbon footprints. Among the chemicals, nitrogen shares practically half of the amount of fertilizers. Furthermore, it is a significant contributor in the release of carbon dioxide aside from biomass.

The measured ozone creation potential is 2.429×10^{-3} kg NOx/kg oil. It is generated from the 3 fuels: biomass at 88.5%, 11.0% diesel and 0.5% gasoline. Similarly, the quantified acidification potential is 0.0138×10^{-3} kg SO_2/kg oil. It is generated from the 3 fuels: across biomass at 77.0%, 22.6% diesel and 0.4% gasoline.

The accounted water footprint is 5,797.3 L/kg oil. This is practically from the rainwater captured in the plantation. It is based on the average 250 mm as rainfall. For the oil mill operations, it has its own water pond to collect rain water. Practically most, if not all, of the water used in both plantation and oil mill comes from rainwater, thereby, it is categorized as green water.

Comparative Environmental Impacts and Performance

To assess the environmental impacts of the oil palm production in North Cotabato, it was compared to six locations among neighbouring countries, which have similar topographical conditions, namely: Sabah and United Plantations Berhad in Malaysia (Norfaradila et al. 2014, Schmidt 2007), Lebak and Medan in Indonesia (Egeskog & Scheer 2016, MOE Indonesia 2014, Siregar et al. 2015), and Southern Area and Krabi in Thailand (Norfaradila et al. 2014, Sampattagul et al. 2011). The equivalent inputs to produce 1 ton of crude oil palm, for both plantation and oil mill operations, are profiled and summarized in Table 5.

Non-renewable energy (NRE) demand of crude oil palm production in North Cotabato was higher than the others except for Lebak, Indonesia as shown in Fig. 2. The main contributor of the NRE were those used in vehicles since biomass is the primary used fuel in production in North Cotabato. For the other locations, they still use fuel in production except for Medan, Indonesia and Krabi, Thailand.

For carbon footprint as summarized in Fig. 3, North Cotabato, Philippines had lower result than four other locations but higher than Sabah, Malaysia and South Thailand. On the lead advantage was Sabah, given that it has the lowest reported use of nitrogen in fertilizers. On the other hand, Krabi, Thailand had the highest carbon footprint given that it has the most amount of used fertilizers. Though, North Cotabato was second after Krabi in terms of nitrogen fertilizers, it had lower carbon footprints due to the amount of biomass used versus the others. Aside from the amount of biomass, the mix of shell and fibre matters since the average specific carbon dioxide emissions were 0.67 kg CO2/kWH for shell while 0.63 kg CO_2/ kWH for fibre. It is worth considering that use of shell biomass to be more efficient since its potential energy has a calorific value of 18.0 MJ/kg, approximately 50% higher than fibre with 12.4 MJ/kg. So, if the share of shell biomass is increased, the amount of biomass should decrease given a stable power generation method. Generally, the oil palm mill requires between 15 kWh and 20 kWh, or an average of 17kWh to process per ton of FFB, depending on fuel usage and power generation methods (Fauzianto 2014, Moller 2012, Yap et al. 2012). Thereby, the optimal amount and mixture of biomass, the better will be the resulting carbon dioxide releases. Another factor to look into is the level of moisture content in fibre and shell biomass, the drier they are the higher are the caloric values.

Table 5: Summary of LCA inventory of inputs and impacts per category among six identified locations.

Inputs	Unit	Cotabato, Philippines	Sabah, Malaysia	UPB, Malaysia	Lebak, Indonesia	Medan, Indonesia	Southern Area, Thailand	Krabi, Thailand
AGRICULTURE								
Fresh Fruit Bunches	kg	5,000.000	5,270.000	5,005.000	4,290.000	4,310.000	5,260.000	5,882.000
Nitrogen (N) from Fertilizer	kg	69.420	6.300	27.585	51.421	23.921	44.000	156.177
Phosphate (P) from Fertilizer	kg	35.863	1.280	18.567	57.474	16.163	12.000	66.933
Potassium (K) from Fertilizer	kg	35.080	9.460	54.108	45.262	31.592	31.000	66.933
Water Consumption (Rainfed)	L	5,793,750.000	8,321,052.632	7,902,631.600	2,492,715.800	3,048,757.900	4,844,736.800	5,758,168.400
Diesel Delivery Consumption to Mill	L	10.670	4.688	-	5.137	2.580	3.606	8.113
Gasoline Delivery Consumption to Mill	L	0.498	-	-	-	-	-	-
OIL MILL								
Oil Extraction Rate	%	20.000	18.975	19.980	23.310	23.202	19.011	17.001
ENERGY CONSUMPTION								
Grid	kWH	-	-	-	-	-	-	-
Diesel	L	-	4.519	3.005	4.520	-	3.606	
Gasoline	L	-	0.076	-	1.780	-	-	-
Biomass	kg	630.000	664.020	1,001.000	780.000	883.550	662.760	741.132
Mesocarp Fibre	kg	567.000	398.412	650.650	600.000	679.654	662.760	741.132
Shell	kg	63.000	265.608	350.350	180.000	203.896	-	-
WATER CONSUMPTION								
Green	L	3,500.000	-	-	-	-	-	-
Blue	L		3,422.500	6,856.850	5,620.000	6,400.000	3,500.000	3,913.878
Gray	L	-	-	-	-	-	-	-
NON-RENEWABLE ENERGY								
Diesel	MJ	377.096	325.397	106.200	341.321	91.186	254.880	286.744
Gasoline	MJ	16.595	2.517	-	59.274	-	-	-
Total	MJ	393.691	327.914	106.200	400.595	91.186	254.880	286.744
Non-Renewable Energy Per kg of Oil	MJ/kg Oil	0.394	0.328	0.106	0.401	0.091	0.255	0.287
CARBON FOOTPRINTS								
Diesel	kg CO_2	28.407	24.512	8.000	25.712	6.869	19.200	21.600
Gasoline	kg CO_2	1.180	0.179	-	4.215	-	-	-
Biomass	kg CO_2	763.155	789.423	1,193.739	937.126	1,061.536	807.936	903.475
Fertilizer, N	kg CO_2	357.513	32.445	142.060	264.816	123.191	226.600	804.313
Total	kg CO_2	1,150.254	846.559	1,343.799	1,231.869	1,191.595	1,053.736	1,729.388
Carbon Emission Per kg of Oil	kg CO_2/kg Oil	1.150	0.847	1.344	1.232	1.192	1.054	1.729
OZONE CREATION								
Diesel	kg NOx	0.266	0.230	0.075	0.241	0.064	0.180	0.203
Gasoline	kg NOx	0.011	0.002	-	0.040	-	-	-
Biomass	kg NOx	2.152	2.226	3.366	2.642	2.993	2.278	2.547
Total	kg NOx	2.429	2.457	3.441	2.923	3.057	2.458	2.750
Ozone Creation kg of Oil	kg NOx/kg Oil × 10^{-3}	2.429	2.457	3.441	2.923	3.057	2.458	2.750
ACIDIFCATION								
Diesel	kg SO_2	0.0031	0.0027	0.0009	0.0028	0.0008	0.0021	0.0024
Gasoline	kg SO_2	0.0001	0.0000	-	0.0002	-	-	-
Biomass	kg SO_2	0.0106	0.0110	0.0166	0.0130	0.0147	0.0112	0.0125
Total	kg SO_2	0.0138	0.0137	0.0175	0.0160	0.0155	0.0133	0.0149
Acidification Per kg of Oil	kg SO_2 /kg Oil × 10^{-3}	0.0138	0.0137	0.0175	0.0160	0.0155	0.0133	0.0149
WATER FOOTPRINT								
Green-Agriculture	L	57,93,750.000	83,21,052.632	79,02,631.579	24,92,715.789	30,48,757.895	48,44,736.842	57,58,168.421
Green-Production	L	3,500.000	-	-	-	-	-	-
Blue-Production	L	-	3,422.500	6,856.850	5,620.000	6,400.000	3,500.000	3,913.878
Total	L	57,97,250.000	83,24,475.132	79,09,488.429	24,98,335.789	30,55,157.895	48,48,236.842	57,62,082.299
Water Footprint Per kg of Oil	L/kg Oil	5,797.250	8,324.475	7,909.488	2,498.336	3,055.158	4,848.237	5,762.082

In terms of ozone creation (Fig. 4), North Cotabato, Philippines was on the lead with the lowest ozone creation potential primarily because it has the lowest amount of biomass used. It was closely followed by Sabah and South Thailand with comparable biomass amounts. UPB and Medan had significantly high amount of NOx levels with more than 3 g NOx/kg oil due to their huge amounts of biomasses. On the other hand, for acidification potential (Fig. 5), North Cotabato, Philippines was third, closely following Sabah and South Thailand. Though it had the lowest amount of biomass versus the top two locations, it had higher amount of diesel used for deliveries, which contributed to accumulating more SO_2. With the other four locations, their acidification potentials were much higher given their biomass amounts plus other fuels used.

Lastly for water consumption (Fig. 6), North Cotabato, Philippines was the only location which relied on green water, basically from rainwater for both plantation and oil mill operations. The other locations utilized blue water from rivers and streams for production. However, for water foot-

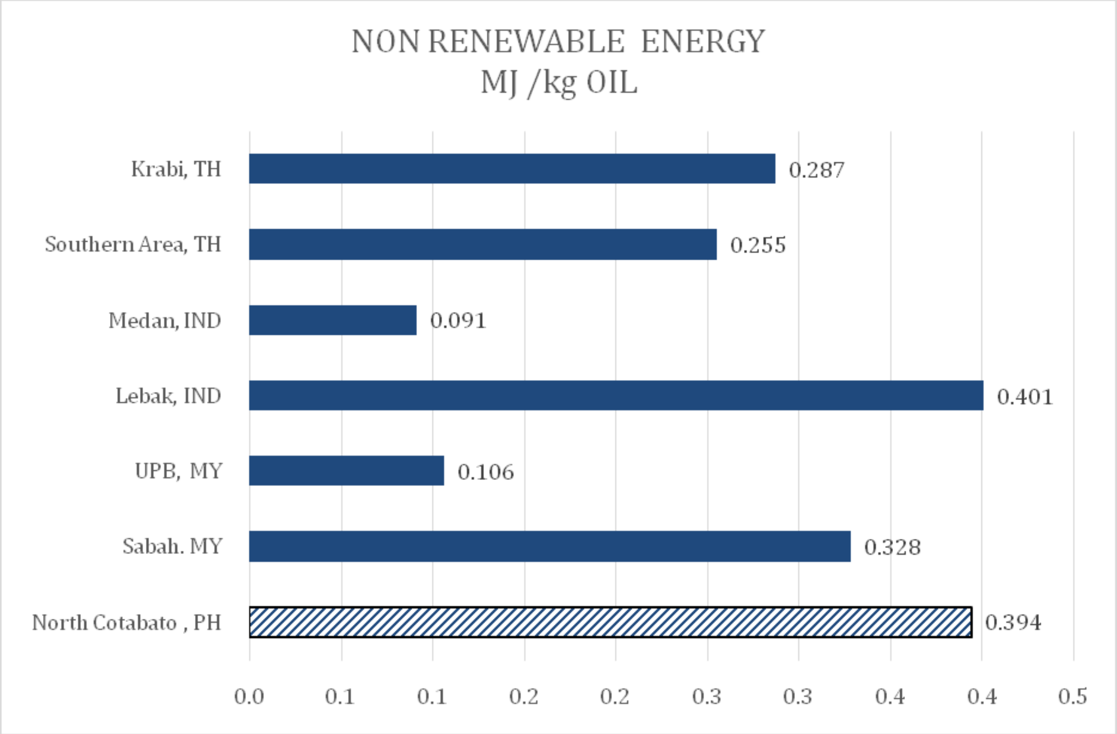


Fig. 2: Comparative non-renewable energy.

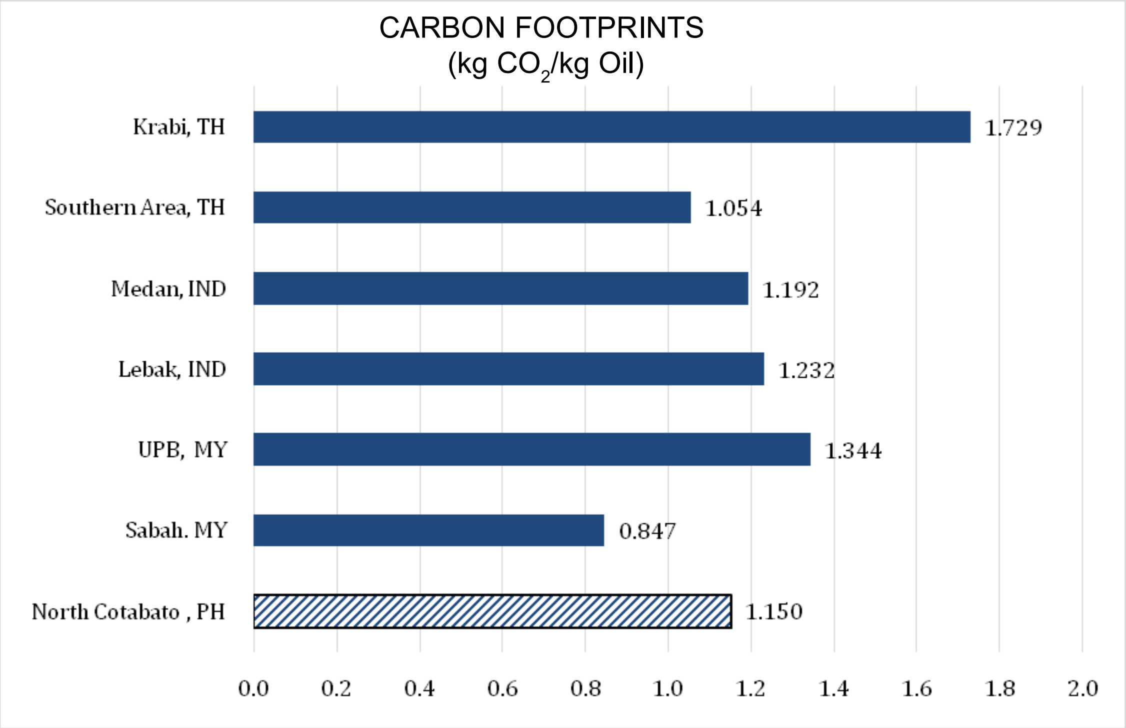


Fig. 3: Comparative carbon footprint equivalent.

print, North Cotabato was only better than the two locations in Malaysia. The locations in Indonesia had lower water footprint since they have high oil extraction rates, average of 23%, which means they use lesser FFBs to be processed for oil. Therefore, the equivalent rainwater used in the plantation was lesser given that one hectare can produce average of 19 tons of FFB per year (Dallinger 2011, ERE Consulting Group 2012). Furthermore, the average rainwater in Medan (92 mm) and Lebak (112 mm) is much lower than the others. The two locations in Thailand follow even if they have comparable oil extraction rates than the rest due to the lower rainfall rates of South Thailand (146 mm) and Krabi (155 mm) versus the average rainfall of 250 mm for those in Malaysia and Philippines (World Weather 2018).

Opportunities to Decrease Environmental Impacts

In general, the environmental impacts of the oil palm production in North Cotabato were satisfactory versus the other 6 locations. To further decrease them, the following opportunities can be undertaken in plantation and oil mill operations.

Oil extraction rates: Increasing OER would mean lesser FFBs to be used in production of crude oil palm. As seen in Indonesian locations, with a high OER of 23% average, there will be lower requirements for delivery of fuel, nitrogen fertilizer and rain water.

Shell for biomass: Increasing amount of shell for biomass coupled with a stable power generation method, would further decrease biomass usage. As discussed, shell has more calorific value potential. Though it releases a slightly higher carbon dioxide emission versus fibre, its potential energy is around 50% higher than shell, which will improve the power generation activities with lesser biomass and equivalent carbon releases.

Fertilizer management: Decreasing the use of amount of nitrogen in the plantation would have a big impact on carbon footprint. The ratio of fertilizer to yield can be improved with prompt and prudent application in the plantation. Techniques on just in time application, precision farming methods, good agricultural practices and the like can be incorporated. Furthermore, proper site selection for palm production should also be considered to avoid unnecessary chemical reinforcements.

FFB deliveries: Optimizing the delivery loads per fuel usage would greatly improve non-renewable energy from the use of diesel and gasoline. Considering the distance of farms and frequency of deliveries, the use of fuel-efficient vehicles with greater loads per delivery would be more efficient in transporting 1 ton of FFBs to the oil mill, as given in Table 2. The oil palm mill and farm owners can consider consolidation and scheduling of delivery to lessen the use of fuels. Thereby, making it more economical as well as lessening the non-renewable energy impacts.

CONCLUSION

The conduct of the LCA in this study was able to measure the potential environmental impacts. Alongside, it provided important insights on where and how they occur as well as improvement options to reduce environmental impacts. Using cradle to gate approach, it was necessary to set the boundary and the inventory to generate the relevant data and information. For the case of North Cotabato, Philippines, the potential environmental impacts were established to be: non-renewable energy of 0.394 MJ/kg oil, carbon footprint of 1.150 $kgCO_2$/kg oil, ozone creation potential of 2.429×10^{-3} kg NOx/kg oil, acidification potential of 0.0138×10^{-3} kg SO_2/kg oil and water footprint of 5,797.3 L/kg oil. Comparing it to six other locations within Indonesia, Malaysia and Thailand gave more meaning as a baseline. The current state and performance relative to environmental impacts were found to be satisfactory given the similar topographical conditions. Lastly, the opportunities to mitigate and decrease the impacts were identified to be: improving oil extraction rates, increasing ratio of shell as biomass fuel, prudent application of nitrogen fertilizers and optimizing delivery loads and schedules. Given that there is no LCA study yet in the country, the case of North Cotabato, Philippines can be a reference for future undertakings on environmental assessments in other locations.

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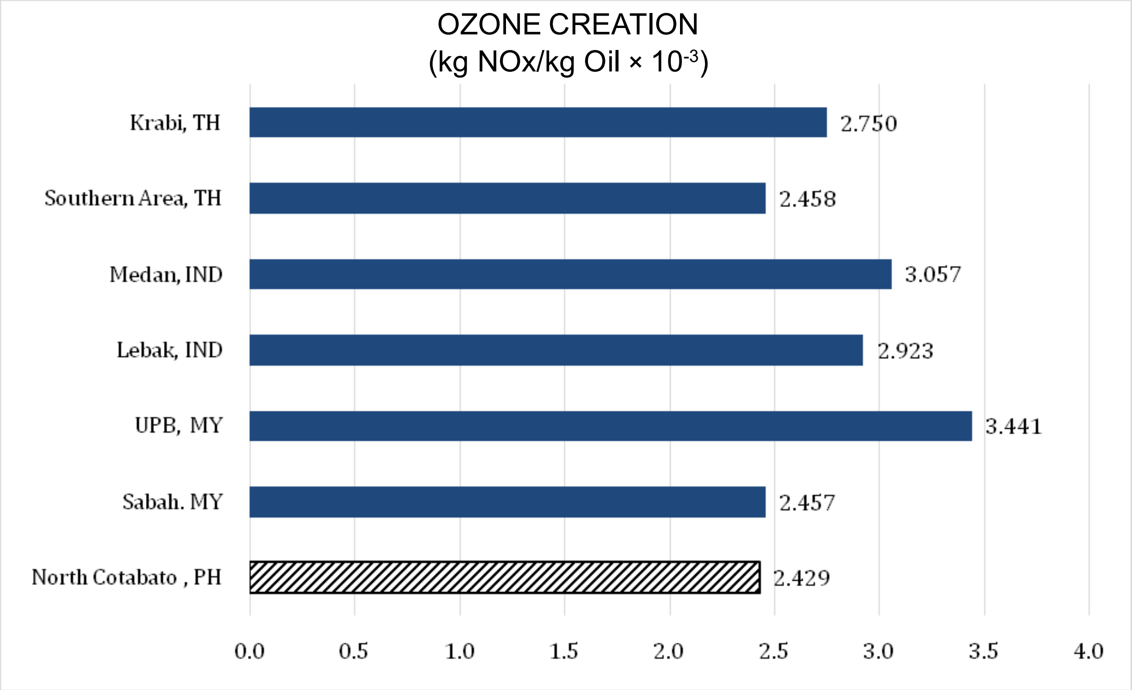

Fig. 4: Comparative ozone creation potential.

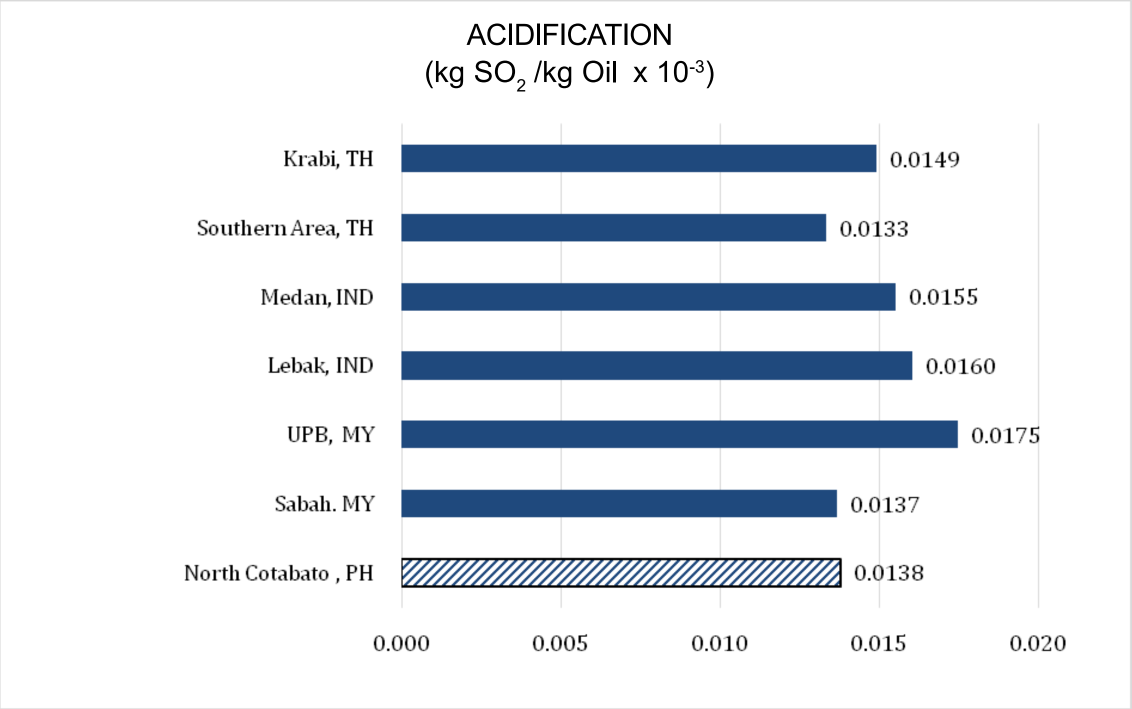

Fig. 5: Comparative acidification potential.

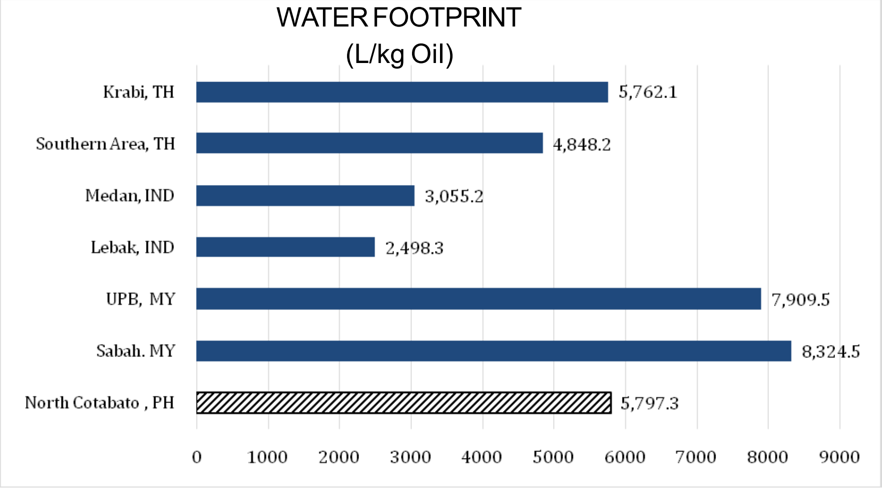

Fig. 6: Comparative water footprint.

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