Potential environment and socio-economic impact of biofuel production in Malaysia: a preliminary review

D Mohan¹, Yusuf Essam¹, H Y B Katman¹, A N Ahmed² and A H Shamsuddin³

¹Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional (UNITEN), 43000 Selangor, Malaysia.
²Institute of Energy Infrastructure (IEI), Universiti Tenaga Nasional (UNITEN), 43000 Selangor, Malaysia.
³Institute of Sustainable Energy (ISE), Universiti Tenaga Nasional (UNITEN), 43000 Selangor, Malaysia.

Corresponding author: dhurgaashinimohan@gmail.com

Abstract. Malaysia is the second-biggest palm oil producer worldwide. Roughly 5.9 million hectares of area is planted with oil palm in Malaysia as recorded in 2019, making the palm oil industry one of the main income-generating industries for the country’s economy. As the palm oil industry in Malaysia grows, concern has been raised as several environmental and socio-economic issues are linked with the expansion of oil palm cultivation. The findings of this research contributes towards the preliminary investigation on the effect of biofuel demand in Malaysia on potential deforestation, greenhouse gas emissions due to land use changes and water pollution due to palm oil mill effluent (POME); and the effect of biofuel demand in Malaysia on other types of crops.

1. Introductions

As the world currently strongly depends on non-renewable fossil fuels, a proper energy management action needs to be developed as soon as possible as these fossil fuels will eventually deplete causing a challenge for the future energy stage. One plausible alternative to address this issue is the presentation and development of sustainable power sources for worldwide utilization.

Renewable energy in the form of biodiesel is an environmentally friendly, newly developed energy source that substitutes fossil fuels with fuel derived from living organisms such as animals and plant crops. The idea of biofuel started when Rudolf Diesel invented the diesel engine in 1900, with peanut oil used as fuel [1]. The recent high demand for renewable fuels has resulted in a huge increase of biofuel production worldwide. Malaysia’s cultivation of oil palms and its palm oil industry helps support the country’s economy and is expected to be a promising alternative fuel to slow down the depletion rate of non-renewable fossil fuels [2]. Palm oil has been proven as a useful product, causing its commercial operations to accelerate.

The growing global demand for palm oil is driven by its wide range of uses, such as cooking oil, food additives, industrial lubricants and, most notably as biodiesel feedstock. In 2018, the Malaysian Palm Oil Board (MPOB) recorded that the total area of oil palm plantations in the country had eclipsed 5.8 million hectares. This is largely due to agricultural land expansion for the cultivation of biofuel feedstock [3]. Great subsidy for biofuel, specifically biodiesel, produced using palm oil, has
promoted the economic growth and cultivation of oil palm in Malaysia since 2005, which has aided the country in meeting national food and fuel needs [4].

Malaysia has an aggregate of 451 plantations effectively delivering millions of tons of unrefined palm oil every year, controlling a large portion of the global palm oil production [5]. The processing of palm oil in Malaysia creates millions of tons of POME annually. POME is generally understood to be a waste product of palm oil processing in palm oil mills, however it is important to understand that POME is composed of up to 75% of methane, which is a flammable gas that can be utilized as a source of renewable energy [6]. The production of POME enables the creation of about 2.4 tons of biogas every year through anaerobic treatments such as ponding [7]. Therefore, POME can contribute towards a circular economy, as this effluent which is generally conceived as a waste product can be processed into a reliable source of bioenergy through the ponding treatment process, before discharging the treated effluent. An assessment on potential environmental and socio-economic impact of biofuel production in Malaysia is not only fundamental for the advancement of bioenergy sources, but also for ideal land usage and management of financial impacts [8].

2. Palm oil and biofuel

2.1. Palm oil

Oil palm, scientifically known as Elaeis guineensis, belongs to the palm family of African palm tribe, known as Arecaceae, and can be used as an oil source. The different varieties of the oil palm fruit can be seen in Figure 1. For practical oil production, the exterior fleshy part, known as the pulp, is steamed to demolish the lipolytic catalysts and afterward squeezed to produce palm oil. The inner most part of the oil palm fruit, known as the kernel, is also squeezed in mechanical screw presses in order to recuperate palm kernel oil, which is synthetically very distinct.

![Figure 1. The variety of oil palm fruit in Malaysia [9].](image)

The oil palm tree has a productive yield ranging from 20 to 30 years and fruits can be sowed as early as 30 months after field planting. This ensures a constant supply of oil. Each ripe fruit bunch is known as a Fresh Fruit Bunch (FFB). The variety of tenera is mainly planted in Malaysia. This variety is a hybrid of dura and pisifera. The tenera variety bears about 4 to 5 tons of crude palm oil (CPO) per hectare each year along with a ton of palm kernels. One ton of oil produced corresponds to only 0.26 hectare of land for seed planting, making oil palm the most cost-effective oil-bearing crop in the world. On the other hand, to produce a similar one ton of oil, crops such as soybean, sunflower, and rapeseed, requires 2.22, 2.0, and 1.52 hectares of land respectively, for seed planting [10,11].
2.2. Palm oil to biofuel
Biodiesel derived from vegetable oil, such as palm oil, soybean oil, and rapeseed oil, is a viable source of renewable energy. Malaysia thus initiates to align the country as a global producer of biofuel derived from palm oil [12]. Figure 2 illustrates the production process of biodiesel.

Figure 2. Process of biodiesel production [13].

3. Impacts of palm oil and biofuel demand

3.1. Potential deforestation and greenhouse gas emissions due to land use change
Palm oil is a significant commodity utilized worldwide in a variety of items for day to day use. Fundamentally, the oil palm tree absorbs carbon from the atmosphere, hence contributing to carbon sequestration, while also providing good foundation to the land it is cultivated in. In Malaysia during the 1990s, the government had introduced restrictions on the expansion of oil palm plantations by pledging to keep at least 50% of its forest cover, as an effort to mitigate deforestation activities and preserve the natural rainforest heritage of the country [14]. In 2019, the Malaysian government limited the national oil palm plantation area to 6.5 million hectares to further combat the threat of deforestation. Today, numerous nations are eager to build their oil palm real estate due to the apparent guarantee of the harvest to be used as feedstock for biofuel or as a substitute for imported oil [15]. These nations are becoming more aware of the benefit of oil palm cultivation especially in rural areas, as the economy in these areas improve through the provision of more employment opportunities for locals and a higher commodity production value.
Figure 3. Plantation areas in Peninsular Malaysia [16].

As of 2019, in Malaysia, oil palm plantations comprise a land territory of 5.9 million hectares. Figure 3 shows the land use with regards to oil palm and other plantations in Peninsular Malaysia and Figure 4 shows the growth of oil palm plantations from year 1960 to 2019. Figure 4 indicates that oil palm plantation areas have increased by more than a hundred times from 1960 to 2019, which is over a period of almost five decades. Oil palm has been a tremendously successful crop in Asia due to its ability to thrive under high insolation rates and rare dry spell periods, such as that in Malaysia [17].

All elements of the oil palm tree are reused or further processed into useful materials. The fronds of an oil palm tree are reused as natural composts and help to improve soil dampness control. Other than that, factory waste such as empty fruit bunch (EFB), pack cinders, POME, and decanter cakes, are reapplied as natural manures for the oil palm plantations. These by-products play a role as soil pH control operators in the peat soil. The filaments or shells that are removed from the FFB are a source wellspring of sustainable power that runs the boilers in palm oil factories. During replanting programs, all the old palm trunks are chopped, hewed, destroyed, protected, and permitted to deteriorate in-situ to develop the suitable soil conditions for new oil palm seeds [20,21].

Palm oil yields in Malaysia are generally between 4 to 4.5 tons per hectare while palm kernel oil yields are about 0.5 tons per hectare. Because of this, the oil palm is regarded as the world's most effective source of vegetable oil [22]. The production of biodiesel through oil palm cultivation in Malaysia has helped in reducing the country’s reliance on fossil fuels while diversifying transport fuels, consequently mitigating GHG emissions [23,24]. As of 2019, Malaysia has implemented mandates for the country’s transport sector to use B10 biodiesel which is a blend of 10% palm oil and 90% petroleum diesel, and the industrial sector to utilize B7 biodiesel which is a blend of 7% palm oil and 93% petroleum diesel. These implementations were stated to boost the national demand for palm oil and reduce GHG emissions by 1.6 million tons annually. Therefore, the usage of land for oil palm cultivation indirectly aids in improving Malaysia’s air quality. The cultivation of an oil palm plantation is capable of absorbing more carbon than it releases under the right conditions. Oil palms are harvested in cycles with a typical life span of 20 to 30 years. If oil palm is planted in a land area with a history of deforestation, maturation, or combustion, which causes low carbon biomass contents,
the oil palm plantation will produce a net carbon sink. In regards with that, some industries and NGOs adopted the High Carbon Stock (HCS) strategy toolbox to preserve carbon stock and monitor GHGs, while also providing stipulations on carbon stock assessment and carbon stock procurement.

![Area of oil palm plantations in Malaysia](image)

**Figure 4.** Growth of Malaysian palm oil plantation area from 1960 to 2019 [18,19].

In a study, rapeseed, sunflower, soybean, and oil palm, were developed on mineral or peat soil to examine their GHG outflows [25]. The investigation indicated that palm oil produced from oil palm trees developed on mineral soils with methane capture has the least GHG outflows per unit biofuel delivered, trailed by soybean oil, sunflower oil, and lastly rapeseed oil. Therefore, when used as an aviation biofuel, oil palm based fuel can have the lowest GHG outflows compared to other equivalent oil crops [26,27].

### 3.2. Water pollution due to palm oil mill effluent (POME)

POME is produced through the extraction process of palm oil from Fresh Fruit Bunches (FFBs) [28]. Essentially, it is a brownish, viscous liquid waste produced in palm oil mills, that has a high biochemical oxygen demand (BOD) and chemical oxygen (COD) [29]. POME also contains high solids concentration and acidity, making it unsuitable for direct discharge into water streams [30]. It is estimated that about 5 to 7.5 tons of water is used for production of one ton of crude palm oil (CPO), with more than 50% of the water converting into POME [31]. This means that for one ton of CPO produced, there will be a POME output of about 2.5 to 3.75 tons. Without proper treatment and waste management, this huge quantity of POME is hazardous and can pollute water streams if authorities are not careful. With the number of palm oil mills increasing in the country [30], the Malaysian government has renewed efforts in managing POME discharges through more demanding regulatory controls.

Due to the concern revolving around POME in Malaysia, mitigation measures and regulatory control over discharges from palm oil mills have been introduced through the Environmental Quality Regulations 1977, promulgated under the Environmental Quality Act 1974 [30]. Ever since the inception of these regulations, palm oil mills have been required to fulfil the requirements prescribed, which are being enforced by the Department of Environment Malaysia (DOE). As a step by DOE to further improve the mitigation of POME discharge in environmentally sensitive areas within Malaysia, the BOD level requirement of industrial effluent intended to be discharge into water streams has become more stringent, with the required BOD level greatly reduced to 20mg/L compared to the previous 100mg/L requirement [32]. Therefore, in order to meet these regulations for discharged
effluent, palm oil mills are required to depend on effective and consistent POME treatment procedures in order to continue operation of palm oil production.

3.3. Other crops’ plantation area growths, productions, and prices
As oil palm plantations increase annually, there have been concerns that the development of other crops may be affected due to the expansion of oil palm. The demand of palm oil and biofuel are speculated to cause a decline in the economy of other important crops in Malaysia, such as rubber, paddy, cocoa beans, and pepper. To analyse this issue, the plantation area data from 2014 to 2018 of the aforementioned crops will first be compared to that of oil palm, as can be seen in Table 1.

Table 1. Plantation area of crops in Malaysia from 2014 to 2018 [18,33].

| Year  | Oil palm (hectares) | Rubber (hectares) | Paddy (hectares) | Cocoa beans (hectares) | Pepper (hectares) |
|-------|---------------------|------------------|------------------|------------------------|-----------------|
| 2014  | 5,392,235           | 1,068,762        | 679,239          | 15,503                 | 16,021          |
| 2015  | 5,642,943           | 1,074,386        | 681,559          | 17,492                 | 16,333          |
| 2016  | 5,737,985           | 1,077,993        | 688,770          | 16,738                 | 16,768          |
| 2017  | 5,811,145           | 1,081,698        | 688,959          | 16,871                 | 17,087          |
| 2018  | 5,849,330           | 1,082,992        | 689,810          | 15,008                 | 17,437          |

Table 1 shows that oil palm, rubber, paddy, and pepper, undergo a net increase in plantation area through the years 2014 to 2018, with cocoa beans the only crop to experience a minor net decrease in plantation area. It can also be noted that in the year 2015, in which the area of oil palm plantations had the biggest annual increase throughout 2014 to 2018, all the other crops also experienced an increase in their respective plantation areas. Other than plantation areas, the production of commodities associated with each crop can also reflect the effect of biofuel demand on other types of crops. The production of each commodity associated with the crops in Table 1, can be seen in Table 2.

Table 2. Production of commodities in Malaysia from 2014 to 2018 [18,33].

| Year  | Crude palm oil (tons) | Natural rubber (tons) | Paddy (tons) | Cocoa beans (tons) | Pepper (tons) |
|-------|-----------------------|-----------------------|--------------|--------------------|--------------|
| 2014  | 19,667,016            | 668,613               | 2,844,983    | 2,636              | 27,500       |
| 2015  | 19,961,581            | 722,122               | 2,741,404    | 1,700              | 28,300       |
| 2016  | 17,319,177            | 673,513               | 2,739,606    | 1,723              | 29,245       |
| 2017  | 19,919,331            | 740,138               | 2,568,102    | 1,012              | 30,433       |
| 2018  | 19,516,141            | 603,329               | 3,064,822    | 814                | 31,073       |

The production of commodities in Table 2 shows that crude palm oil, natural rubber, and cocoa beans, experienced a net decrease in production, with the production of cocoa beans experienced a huge decrease, reducing by more than three times. On the other hand, paddy and pepper had a net increase in production. To determine whether palm oil and biofuel demand has any effect on the economy of each commodity, the price of each commodity throughout the years must also be analyzed. The prices of each commodity from 2014 to 2018 can be seen in Table 3.

Based on Table 3, it can be seen that the prices of all commodities, except for paddy, experienced a net decrease in price from 2014 to 2018, with cocoa beans and pepper decreasing drastically in price by thousands of RM per ton. It can also be noted that the price of paddy remains stagnant at RM1200. This is due to the Ministry of Agriculture and Agro Based Industries Malaysia setting a fixed buying price for paddy at RM1200 back in 2014 [34].
Table 3. Price of commodities in Malaysia from 2014 to 2018 [23,24]

| Year | Crude palm oil (RM/ton) | Natural rubber grade SMR20 (cent/kg) | Paddy (RM/ton) | Cocoa beans (RM/ton) | Pepper Black (RM/ton) | Pepper White (RM/ton) |
|------|------------------------|-------------------------------------|----------------|----------------------|----------------------|-----------------------|
| 2014 | 2,383.50               | 553.13                              | 1,200          | 8,525.67             | 22,516               | 32,345                |
| 2015 | 2,153.50               | 521.90                              | 1,200          | 8,004.67             | 28,031               | 43,784                |
| 2016 | 2,653.00               | 568.45                              | 1,200          | 8,326.67             | 26,400               | 43,114                |
| 2017 | 2,783.00               | 703.71                              | 1,200          | 6,117.33             | 16,275               | 25,402                |
| 2018 | 2,232.50               | 543.56                              | 1,200          | 6,113.00             | 10,292               | 16,984                |

4. Discussion

From an analytical perspective, the procedure for land use arrangement and advancement is generally feeble, if through singular plantation organizations. To evaluate the GHG emissions from direct Land-Use Change (LUC), the carbon stock changes of all pools must be calculated based on the 2006 IPCC rules. The pools consider the change in biomass contents, adjustments in dead natural issue, shifts in soil carbon stocks from land clearing preceding oil palm development and non-carbon dioxide outflows from biomass consumption that is utilized to clear the land [35].

The regulations enforced by the Department of Environment Malaysia have addressed the threat of POME in the country, with many palm oil mills adopting an anaerobic digestion method known as ponding, to treat POME before discharge [36]. The ponding technique is the conventional method of treating POME in Malaysia, which produces biogas. The ability for POME to be converted into biogas is due to the high organic content of POME, which means a higher amount of feedstock for anaerobic digestion, hence producing a higher volume of methane gas. With each ton of POME capable of producing up to 28m$^3$ of biogas, about 2.4 tons of biogas capable of being produced annually. This is equivalent to the amount of energy that could be generated by 3.4 million litres of diesel or 13,600 MWh [7]. The Malaysian government has realized the huge potential of POME as a renewable energy source in the form of biogas and has encouraged the country’s palm oil mills to facilitate effective biogas generation and capture for utilization as an on-site energy source for electricity generation [37]. Therefore, the anaerobic digestion method, that is ponding, implemented in Malaysia is a way to benefit from the treatment of POME for discharge into water streams, by harnessing biogas that will improve the economic performance of the palm oil mill, while also reducing greenhouse gas emissions due to palm oil production processes.

As the plantation area of oil palm increases, all the other crops also increase in plantation size annually, with the exception of cocoa beans, as can be seen in Table 1. Cocoa beans not only reduced in plantation area, but also experienced a decrease in production by more than three times, and a decrease in price by almost 30 percent. Therefore, it is clear that the economy of cocoa beans in Malaysia went through a recession between 2014 and 2018. The decline of the cocoa bean economy stretches all the way back after the industry peaked in the 1990s, during which cocoa beans had low production costs and good selling prices, with production reaching 247,000 tons [38]. The price of cocoa beans started its first decline between 1986 and 1993, reducing from RM4,260 per ton to RM2,314 per ton [38]. The prices eventually started climbing again, until 2014 when it reached its peak at about RM8,525 in 2014, and is continuing its decline with the price now RM6,113 per ton. The price of cocoa beans is well-known to be volatile, however its decline is largely associated with untreatable pest and disease problems such as the infestation of Cocoa Pod Borers (CPD) which decreases cocoa bean profitability [38–40]. According to the World Cocoa Foundation (WCF), it is estimated that between 30% to 40% of cocoa production losses in major cocoa growing nations are caused by pest and disease infestation [41]. On top of that, labour issues are also a factor in the recession of the cocoa bean industry. With most hired labourers being short-term migrants,
smallholders are discouraged from monetary investments for their labourers’ training, hence good agricultural techniques are not able to be developed causing poor productivity and quality of cocoa beans [39,41] As rice is a food staple in Malaysia, concerns over competition for plantation area between paddy and oil palm can be alleviated as it can be seen that both crops increase in plantation areas between 2014 to 2018. The productions of both crops are also healthy as paddy production goes through a net increase from 2014 to 2018, with crude palm oil production remaining steady above 19,000,000 tons with the exception of production in the year 2016, as can be seen in Table 2. This indicates that production of rice, which is an important food for Malaysians, is able to co-exist with oil palm, which is an important fuel source. Lastly, it can be noted that both black pepper and white pepper undergo a huge reduction in price from 2014 to 2018 as can be seen in Table 3. This is understood to be largely due to the high increase of pepper prices between 2014 to 2015, which prompted many regional growers in Southeast Asian countries such as Vietnam, Malaysia, and Indonesia, to start planting pepper trees. This influx of pepper growers caused the global pepper supply to increase tremendously, which in turn caused the pepper prices to decrease annually due to the pepper supply greatly outweighing the pepper demand.

5. Conclusion
This study was performed as a preliminary investigation on the effect of biofuel demand in Malaysia on potential deforestation, greenhouse gas emissions due to land use changes and water pollution due to palm oil mill effluent (POME); and the effect of biofuel demand in Malaysia on other types of crops. Biofuel demand and oil palm expansion in Malaysia is continuously being observed and controlled by the government, as restrictions are put in place to prevent the expansion of oil palm plantations and deforestation activities at unhealthy rates. Through oil palm cultivation, the production of biodiesel has helped the country in reducing reliance on fossil fuels. With the Malaysian government stipulating the use of B10 biodiesel and B7 biodiesel for the transport sector and the industrial sector respectively, GHG emissions were determined to reduce by 1.6 million tons annually. Through a higher palm oil demand and production rate, higher reductions in GHG emissions could be achieved in the future through a higher blend of palm oil in biodiesel. This means that the usage of land for oil palm cultivation aids the country in reducing its GHG emissions in the long run. The threat of water pollution due to POME has been further mitigated through the introduction of more stringent discharge requirements from the DOE in Malaysia, with the BOD requirements of discharge set to 20mg/L from the previous 100mg/L. POME treatment in Malaysia is conventionally performed through anaerobic digestion using the ponding technique. The ponding technique has allowed the generation of biogas which helps for on-site electricity generation and reduction of GHG emissions due to palm oil production processes. The socio-economic side of this study shows that oil palm cultivation does not appear to affect other crops according to the available statistics in Table 1, Table 2, and Table 3. The recession of the cocoa bean economy has been determined to be due to pest infestation and labour issues, while the drop in pepper price was determined to be because of the influx of global pepper supply. The statistics also show that the country’s food staple, which is rice, is not under threat due to oil palm cultivation, as both crops increase in plantation areas from 2014 to 2018, with healthy production rates for both of the crops throughout the five years.

Acknowledgement
The authors would like to acknowledge the financial support received from AAIBE Chair of Renewable Energy, Institute of Sustainable Energy (ISE), Universiti Tenaga Nasional (UNITEN), Malaysia under grant code: 201902KETTHA.

References
[1] Hambali D, Abdu B, Ibrahim A A and Muhammad I 2016 The global environmental impacts of palm oil biodiesel production on global warming (A Review) IRF Int. Conf. 45–7
[2] Lim C I, Biswas W and Samyudia Y 2015 Review of existing sustainability assessment
methods for Malaysian palm oil production *Procedia CIRP* **26** 13–8

[3] Chin M 2011 *Biofuels in Malaysia: An analysis of the legal and institutional framework*

[4] Mukherjee I and Sovacool B K 2014 Palm oil-based biofuels and sustainability in southeast Asia: A review of Indonesia, Malaysia, and Thailand *Renew. Sustain. Energy Rev.* **37** 1–12

[5] Abdullah I, Wan Mahmood W H, Fauadi M H F M, Rahman M N A and Ahmad F 2015 *Sustainability in Malaysian palm oil: A review on manufacturing perspective* Polish J. Environ. Stud.

[6] Aipassa M I, Kristiningrum R and Tarukan V Y 2018 Prospect and policy of palm oil mill effluents for future electricity in East Kalimantan (utilization of pome as renewable energy) *IOP Conf. Ser. Earth Environ. Sci.* **144**

[7] Izzah N, Aziz H A and Hanafiah M M 2017 the potential of palm oil mill effluent (pome) as a renewable energy 1 9–11

[8] Kochaphum C, Gheewala S H and Vinitnantharat S 2015 Does palm biodiesel driven land use change worsen greenhouse gas emissions? An environmental and socio-economic assessment *Energy Sustain. Dev.* **29** 100–11

[9] Food and Agriculture Organization of the United Nations 1970 the oil palm (Food and Agriculture Organization of the United Nations)

[10] Johari A, Nyakuma B B, Mohd Nor S H, Mat R, Hashim H, Ahmad A, Yamani Zakaria Z and Tuan Abdullah T A 2015 The challenges and prospects of palm oil based biodiesel in Malaysia

[11] Yusuf N N A N, Kamarudin S K and Yaakub Z 2011 Overview on the current trends in biodiesel production, *Energy Convers. Manag.*

[12] Yee K F, Tan K T, Abdullah A Z and Lee K T 2009 Life cycle assessment of palm biodiesel: Revealing facts and benefits for sustainability, *Appl. Energy*

[13] Wahyono Y, Hadiyanto H, Budihardjo M A and Adiansyah J S 2020 Assessing the environmental performance of palm oil biodiesel production in Indonesia: A life cycle assessment approach *energies* **13** 3248

[14] Varkkey H, Tyson A and Choiruzzad S A B 2018 Palm oil intensification and expansion in Indonesia and Malaysia: Environmental and socio-political factors influencing policy For. Policy Econ. **92** 148–59

[15] Lam M K, Lee K T and Rahmanmohamed A 2009 Life cycle assessment for the production of biodiesel: A case study in Malaysia for palm oil versus jatropha oil *Biofuels, Bioprod. Biorefining*

[16] Shevade V S and Loboda T V. 2019 Oil palm plantations in Peninsular Malaysia: Determinants and constraints on expansion ed G R Clements *PLoS One* **14** e0210628

[17] Sumathi S, Chai S P and Mohamed A R 2008 Utilization of oil palm as a source of renewable energy in Malaysia *Renew. Sustain. Energy Rev.*

[18] Ministry of Primary Industries Malaysia 2019 *Commodities fact sheet Q1 2019*

[19] Rosli F, Ruzaidi C, Abdullah M A and Kamarudin H 2016 A review: Characteristics of oil palm trunk (OPT) and quality improvement of palm trunk plywood by resin impregnation

[20] Achten W M J and Verchot L V. 2011 Implications of biodiesel-induced land-use changes for CO2 emissions: Case studies in Tropical America, Africa, and Southeast Asia *Ecol. Soc.*

[21] Wicke B, Sikkema R, Dornburg V and Faaij A 2011 Exploring land use changes and the role of palm oil production in Indonesia and Malaysia *Land use policy*

[22] Kushairi A, Ong-Abdullah M, Nambiappan B, Hishamuddin E, Bidin M N I Z, Ghazali R, Subramaniam V, Sundram S and Parveez G K A 2019 *Oil palm economic performance in Malaysia and r&d progress in 2018* J. Oil Palm Res.

[23] Sheehan J, Camobreco V, Duffield J, Shapouri H, Graboski M and Tyson K S 2000 *An overview of biodiesel and petroleum diesel life cycles* (Golden, CO (United States))

[24] Intal Jr P S, Oum S and Simorangkir M J O 2011 *Agricultural development, trade and regional cooperation in developing East Asia* (Jakarta)
[25] Teoh C H 2002 The palm oil industry in Malaysia: From seed to frying pan WWF
[26] Awang Ali B D N, Kunjappan R, Chin M, Schoneveld G, Potter L and Andriani R 2011 The local impacts of oil palm expansion in Malaysia: an assessment based on a case study in Sabah State. CIFOR Work. Pap.
[27] Lam W Y, Kulak M, Sim S, King H, Huijbregts M A J and Chaplin-Kramer R 2019 Greenhouse gas footprints of palm oil production in Indonesia over space and time Sci. Total Environ.
[28] Borja R and Banks C J 1995 Comparison of an anaerobic filter and an anaerobic fluidized bed reactor treating palm oil mill effluent Process Biochem. 30 511–21
[29] Poh P E, Yong W-J and Chong M F 2010 Palm Oil Mill Effluent (POME) Characteristic in high crop season and the applicability of high-rate anaerobic bioreactors for the treatment of POME Ind. Eng. Chem. Res. 49 11732–40
[30] Chin M J, Poh P E, Tey B T, Chan E S and Chin K L 2013 Biogas from palm oil mill effluent (POME): Opportunities and challenges from Malaysia’s perspective Renew. Sustain. Energy Rev. 26 717–26
[31] Latif Ahmad A, Ismail S and Bhatia S 2003 Water recycling from palm oil mill effluent (POME) using membrane technology Desalination 157 87–95
[32] Liew W L, Kassim M A, Muda K and Loh S K 2012 Insights into efficacy of technology integration: the case of nutrient removal from palm oil mill effluent Proceedings of UMT 11th international annual symposium on sustainability science and management pp 1203–11
[33] Department of Agriculture Malaysia 2018 Food Sub-Sector Plantation Statistics 2018
[34] Ministry of Agriculture and Agro-Based Industry Malaysia 2014 Stipulation of fixed paddy buying price in Peninsular Malaysia at RM1,200/metric ton
[35] Poh C, Kanniah K D and Loong C K 2016 Monitoring oil palm plantations in Malaysia International Geoscience and Remote Sensing Symposium (IGARSS)
[36] Chan Y J and Chong M F 2019 Palm Oil Mill Effluent (POME) Treatment—Current Technologies, Biogas Capture and Challenges Green Technologies for the Oil Palm Industry pp 71–92
[37] Choong Y Y, Chou K W and Norli I 2018 Strategies for improving biogas production of palm oil mill effluent (POME) anaerobic digestion: A critical review Renew. Sustain. Energy Rev. 82 2993–3006
[38] Mohamed Arshad F and Ibragimov A 2015 Malaysia’S cocoa beans decline: a Prognosis Int. J. Agric. For. Plant. 1 1–14
[39] Azhar I 2007 The Ways towards Sustainability of Cocoa Industry in Malaysia.
[40] Hebbas P K 2007 Cacao Diseases: A Global Perspective from an Industry Point of View Phytopathology® 97 1658–63
[41] Omar S C, Bee Y G and Sazali N T 2018 A Monograph of a Malaysian Cocoa Smallholder: Working Paper

Acknowledgement
The authors would like to appreciate the technical and financial support received from research grant coded 201902KETTHA by AAIBE Chair of Renewable Energy, Innovation & Research Management Center (iRMC), Universiti Tenaga Nasional (UNITEN).