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Biofuel Development in Malaysia: Challenges and Future Prospects of Palm Oil Biofuel

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ABSTRACT

Biofuels have received a lot of interest as a result of rising energy demand which caused rapid depletion of fossil fuels and growing worries about greenhouse gas emissions. Biofuels, unlike other renewable energy sources, can supply liquid fuels, which are necessary for transportation. In this review study, the main focus is the scenario of palm oil biofuel development in Malaysia, which involves the future prospect and challenges faced by the country to fully-utilize the potential of palm oil as a renewable energy. Even with the primary driving policy, the National Biofuel Policy 2006, it is found that as of the year 2020, Malaysia is still lacking in pace and technologies in inventing top-notch quality biofuel. Although the number of articles published in the subject of biofuels is increasing, more study is required to explain current technology and its benefits, especially in Malaysia, the world's second-largest producer of oil palm.

Keywords: Biofuel, biomass, challenges, palm oil, policy

1. INTRODUCTION

1.1 Biofuels as an Alternative to Fossil Fuels

Every day, the world's energy consumption increases and causing natural resources such as the fossil fuels to deplete in worrying rate [1], [2]. Apart from that, this scenario leads to changes in the global climate, which were regarded as one of the most critical concerns facing the planet in the twentieth century. According to Liaquat *et al*. [3], if the average global temperature rises by more than 2°C, hundreds of millions of people will perish [4]. Much of the world's human greenhouse gas emissions come from energy-related carbon dioxide emissions, such as those produced by the combustion of liquid fuels, natural gas, and coal. As a result, energy use is a significant part of the global climate change discussion. This situation has driven worldwide growth of renewable energy sources that is compelled by the global commitment to climate change mitigation [5]. Thus, some of the gaps left by the depleted fossil fuel resources could be filled by biofuels, while simultaneously mitigating the global warming issue [6]. As many nations move toward sustainable world development, the conversion of organic and inorganic wastes into useful and valuable end products such as biohydrogen, biomethane, and bio alcohols is being more studied each year.

The overuse of conventional fuels, as well as their detrimental environmental effects, has sparked a global demand for biomass-based liquid fuels. Moreover, as a result of the depletion of fossil fuels, biofuel generation from renewable sources has grown in popularity. Apart from that,

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biofuel also have significant advantages compared to fossil fuel as shown in Table 1. Malaysia has a lot of potential for manufacturing various biofuels from renewable sources because it is a tropical country with a lot of natural resources. In Malaysia, biofuels can be created from a range of sources, including lignocellulosic biomass, palm oil leftovers, and municipal waste. Thus, in this paper, the main focus is the scenario of palm oil biofuel development in Malaysia, which involves the future prospect and challenges faced by the country to fully-utilize the potential of palm oil as a renewable energy.

Table 1 Comparison between Biofuels and Fossil Fuels [7]

Issues	Biofuel	Fossil Fuel
Time taken	Short period of regeneration	Millions of years to generate in the earth
Renewable/non-renewable	Renewable	Non-renewable
Pollution	Environmental-friendly	Pollution of the environment occurs in a variety of ways
Production	Produced on a small to large scale with ease	Cannot be produced – generated naturally
Effect on human health	Less health issues	High health hazard

1.2 Production of Biofuels

Biofuels can be liquid (bioethanol and biodiesel) or gaseous (biogas) (biohydrogen and biogas). Organic materials (biomass) which includes plants and animal waste are used to produce biofuels which are non-fossil fuels. These biofuels can be made in a liquid state like biodiesel, ethanol, and biogas or in a solid state like charcoal and wood chips [7], [8]. Four categories of biofuels, which are the first, second, third, and fourth-generation are classified according to the biological feedstocks they were extracted from [9] as can be seen in Table 2. Two of the most common produced biofuels are the first-generation and second-generation of biofuels where the first are mainly produced from food or free-based crops through hydrolysis and fermentation processes or tans-esterification while for the latter the feedstocks are mostly from non-food crops and residues or waste materials [10] as illustrated in
Figure **1**. Furthermore, second or third generation of biofuels are also known as advanced biofuels, where the feedstocks are from plant material which cannot be consume as food [8]. For third-generation of biofuels, the feedstocks are also non-food materials, especially algae. Although third-generation of biofuels are also made from non-food feedstocks as for the second-generation, they have been classified by researchers under a specific category since algae have a much higher yield with significantly lower resource inputs compared to the other feedstocks of second-generation biofuels. The fourth-generation of biofuel, on the other hand, aims to provide sustainable energy while also absorbing and storing CO2 using genetically modified feedstocks [6].

Table 2 Classification on the Biofuels on the Basis of Feedstock Used for Production [11]

Biofuel	First-generation	Second-generation	Third-generation	Fourth-generation
Feedstocks	Major food crops and edible oils (palm oil, rapeseed oil, soy bean oil, cottonseed oil,	Energy crops Waste products (jatropha, camelina, willow, poplar, straw, food	Microalgae Animal tallow Waste cooking oil	Photo biological solar biodiesel Electro-biofuels

	sugar cane, wheat, potato, corn)	waste, wood waste, manure)		

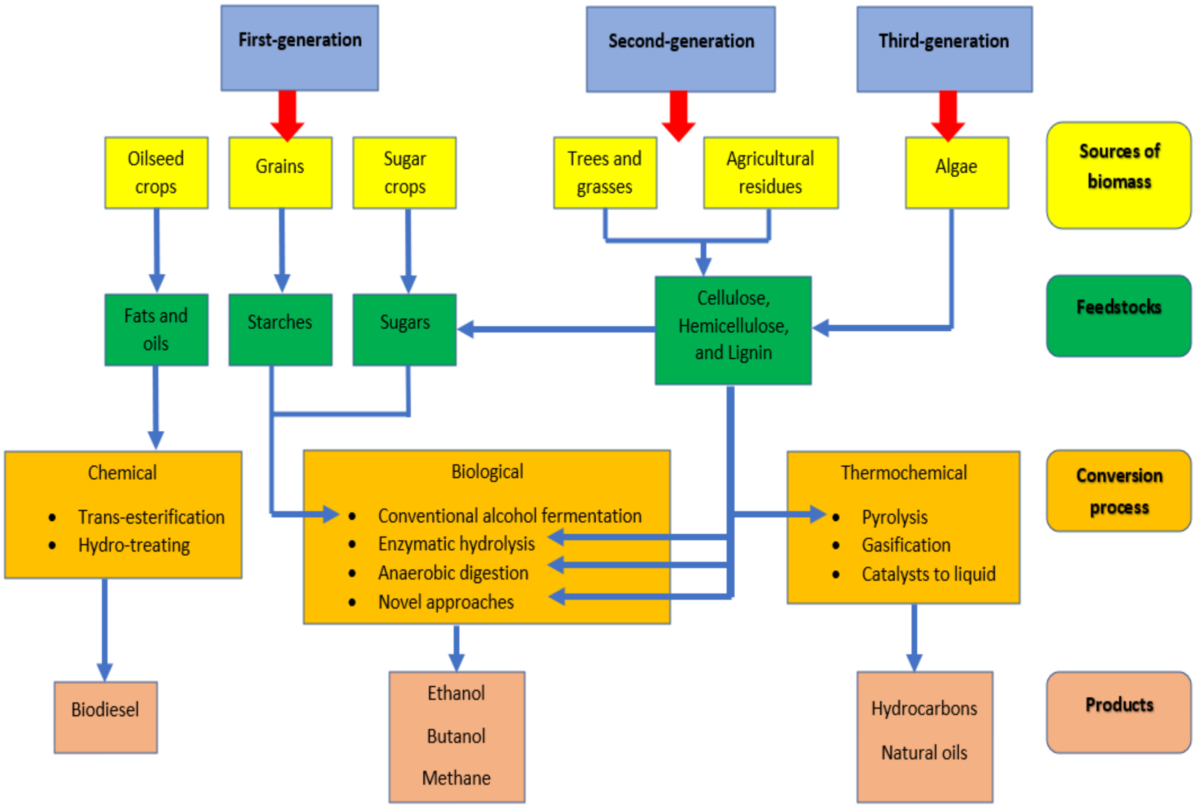

Figure 1. Biofuels production process (Reconstructed from Mofijur *et al*., 2015). [12]

According to Singh *et al*. [13], several factors must be taken into account when evaluating edible biomass for biofuel production as listed below. These factors have huge effect on the biofuel development in Malaysia especially in the term of obstacles faced;

- Competition with food needs
- Availability of croplands and the contribution to biodiversity and cropland value losses
- Impact of mineral absorption on water resources and soil
- Emission of pollutant gases
- Soil erosion
- Energy balance
- The biomass chemical composition
- Cost of the biomass and its transport and storage
- Cultivation practices
- Economic evaluation considering both the coproducts and feedstocks
- Resource availability such as water
- Creation or maintenance of employment
- Use of pesticides

1.3 Malaysian Palm Oil Biomass

Oil palm (*Elaeis guineensis*) has its origin in West Africa, where it was once thought to be a native plant beneficial for a variety of purposes. Its cultivation has since expanded around the world, particularly in the South American and Asian continents [14], [15]. Nigeria was the world's leading producer of palm oil until the mid-1960s [16], when Malaysia's palm oil production overtook Nigeria as a result of the oil palm industry's rapid expansion. Malaysia was the world's leading producer and exporter of palm oil and related goods until 2007, when Indonesia overtook it [17], [18]. The oil palm tree is very popular in Indonesia and Malaysia as the plant thrives in tropical climates with lots of rain [15]. Furthermore, about 85% of entire palm oil produced globally by these two nations, with Indonesia and Malaysia contributing 44% and 41% of yield, respectively [19]. Table 3 shows the land area that have been utilized for palm oil plantation in Malaysia, as of year 2015-2019. It can be seen that the total plantation area increases each year, for Peninsular Malaysia and Sabah and Sarawak. This indicates that Malaysia has an abundant availability of palm oil and as of year 2009, more than 300 palm oil mills in Malaysia are currently powered by self-generated electricity from oil palm biomass [20]. Furthermore, ongoing palm oil mills expansion, accelerated replanting activity, and improved oil extraction rate in the country would further increase the availability of palm oil biomass [21]. In fact, in November 2011, the Prime Minister and the Minister of Plantation Industries of Malaysia launched the National Biomass Strategy 2020. By mobilising 30 million tonnes of biomass by 2020, one of the strategy's main goals is to identify specific opportunities and enablers for building high-value industries [22].

Table 3 Oil Palm Plantation Area in Malaysia [23], [24]

State	Plantation Area (million hectares/year)				
	2015	**2016**	**2017**	**2018**	**2019**
Peninsular Malaysia	2.3	2.3	2.4	2.4	2.8
Sabah and Sarawak	2.6	2.7	2.7	2.8	3.1
Total	4.9	5.0	5.1	5.2	5.9

As mentioned by Mahlia *et al*. [25], biomass may be used to make a variety of biofuels, known as bioethanol, biomethanol, biohydrogen (biogas), biobriquettes, and pyrolysis oil respectively. Another researcher, Correa *et al*. [26], explained that biofuels are categorized into four types which are biodiesel, bioethanol, biogas, and biohydrogen. These fuels can be derived from variety of sources, including food-based or non-food-based crops and waste-based materials. For palm oil in particular, its biomass remainder is categorized into six types. They are known as oil palm frond (OPF), oil palm trunk (OPT), empty fruit bunch (EFB), mesocarp fibre, palm kernel shell (PKS) and palm oil mill effluent (POME)[27].

In the current literature, Faizal *et al*. [28] agreed that industrial scale production and utilization of biodiesel in Malaysia has the justifications to be supported as there are abundant palm oil resources in the country. Onoja *et al*. [29] also mentioned that Malaysia's oil palm sector is the country's main source of biomass as they possesses abundant availability in this country. This is in agreement with Shuit *et al*. [20] and Umar *et al*. [30] who identified that palm oil biomass contributes about 85% in various industries in Malaysia as can be seen in
Figure **2**. This shows that palm oil agriculture is vital in the renewable biomass production in this country and this makes them a main contributor to the entire capacity target in the FiT (Feed-in Tariff) [31] policy system. Statistics produced by Index Mundi [32] in
Figure **3** also indicates that Malaysia is producing more than 11 million metric ton of palm oil yearly, as of year 2001-2021. Recently, in year 2021, the Malaysian crude palm oil price reached the highest price per metric ton since the year 2001 as presented in
Figure **4**. These statistics proved that palm oil sector is still one of the main key contributors towards Malaysian economy [33].

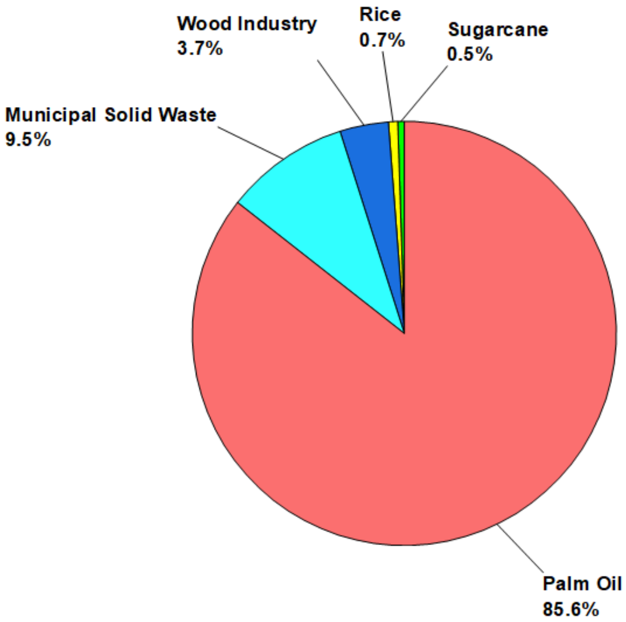

Figure 2. Biomass produced from different industry in Malaysia. [20]

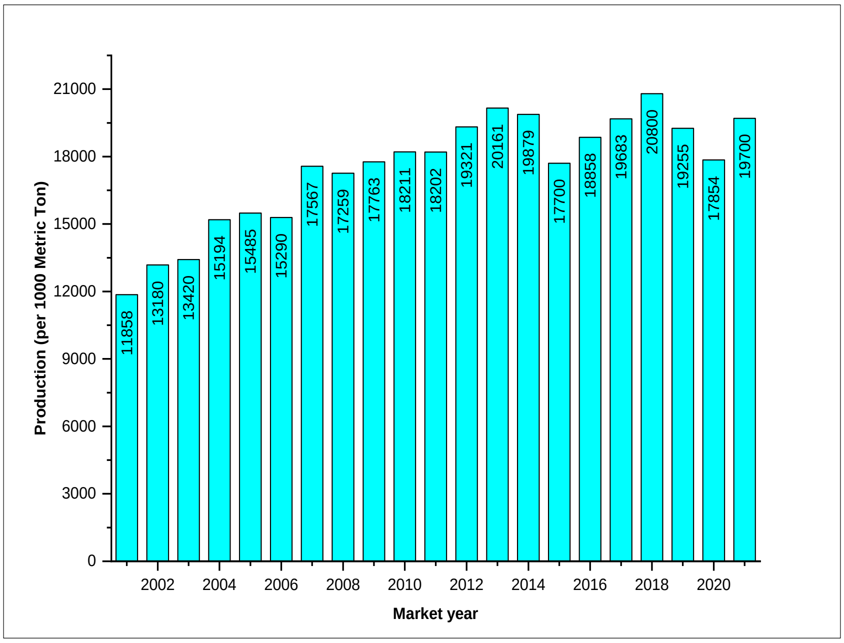

Figure 3. Malaysia palm oil production by year (Reconstructed from Index Mundi). [32]

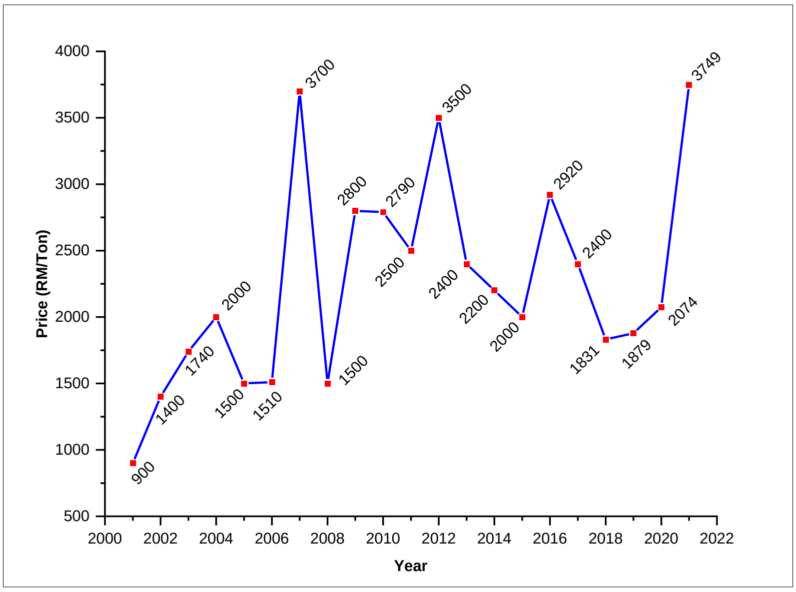

Figure 4. Crude palm oil price statistics. [32], [34]–[36]

The current leading producer of biodiesel is Germany, followed by USA. In Germany, the main sources of biodiesel are rapeseed, while soybeans are mostly used in USA [6]. In Malaysia, palm oil biodiesel is the type of biofuel that is mostly used especially in the transportation sector, as transportation sector plays a vital part in supporting the expansion of the palm oil sector whereby a well-functioning transportation system expands economic and social possibilities [37]. Mahlia *et al*. [25] identified that among other types of biofuels, biodiesel and bioethanol have the largest potential to replace fossil fuel in gas turbine operation. Research finding by Mofijur *et al*. [12] also points towards the potential of biodiesel and bioethanol as the two most promising biofuels being reckoned as alternatives for the conventional fossil fuels in transportation sectors. In general, biodiesel or fatty acid methyl ester (FAME) is commonly produced through transesterification process which involves blending of vegetable oils with methanol and the help of proper catalysts. The end product of this process, which is biodiesel can be implemented in compression-ignition (CI) engine to replace the petroleum diesel, without the need of any major engines modifications as the biodiesel has almost identical properties to that of petroleum diesel. On the other hand, the conventional bioethanol is produced mainly by the process of fermentation of simple sugar or starch crops. The end product of this process is applied in petrol engine as replacement for gasoline.

Biodiesel in Malaysia is produced under the Promotion of Investment Act 1986. Malaysia has had a comprehensive biofuel program since 1980s. Palm oil has high use potential because of its high yield per hectare and high oil content. Its production per hectare is 27 times higher than other oil seeds [38], [39]. Since 1980s, the transesterification of crude palm oil into palm oil diesel (POD) has been pioneered by the collaboration of Malaysian Palm Oil Board (MPOB) and the local giant oil company, PETRONAS [40]. Joint effort between these two organisations is one of the catalysts in producing and promoting decent quality of biodiesel blends in Malaysia. With years of collaboration with PETRONAS, MPOB has manged to produce B10 biodiesel that fulfils the international qualification standards, namely ASTM D6751 (United States) and EN14214 (Europe). The comparison of global biofuel standard is shown in Table 4. By meeting these standards, the biodiesel is safe to be used in all diesel vehicles without the need to modify the engine. Moreover, the power supplied by the B10 biodiesel is comparable to that of mineral diesel when MPOB with the Road Transport Department carried out a test on a dynamometer using the B10 fuel [34]. Other benefits and drawbacks from using biodiesel is presented in Table 5.

Table 4 Comparison of Biofuel Standards around the World [41]–[44]

Parameters	Malaysia	USA (ASTM)	Germany (DIN)	Austria (ON)	Brazil ANP 42	France	Korea
Density at 15°C (g/cm^3)	0.8783	-	0.875-0.89	0.85-0.89	0.87-0.89	0.87-0.89	0.86-0.89
Viscosity at 40 mm^2/s	4.415	1.9-6.0	3.5-5.0	3.5-5.0	-	3.5-5.0	1.9-5.5
Flash point (°C)	182	130	110	100	100	100	>120
Pour point (°C)	15	-	-	-	-	-10	-
Cetane number	56	≥47	≥49	≥49	-	≥49	-

Table 5 Advantages & Disadvantages of Biodiesel [45]–[49]

Advantages	• Generates fewer pollutant emissions such as CO2, PM, and HC compared to diesel • Its production is easier and faster than diesel • It has shown better performance in vehicles due to its higher-octane number • It helps to prolong engine life and minimizes the engine maintenance required • Unlike diesel engine, it does not need additional lubricant to be used • It has a magnificent potential for stimulating sustainable rural development and as a solution for energy security issues • It has a higher cost efficiency than diesel • Unlike diesel, it does not require any drilling, transportation or refinement • Compared with diesel fuel, it has better sulfur content, flash point, aromatic content, and biodegradability • It is safer to handle and less toxic than diesel fuel • It is non-flammable, non-toxic, and it reduces tailpipe emissions, visible smoke and noxious fumes and odors • It does not require any engine modification • It has high combustion efficiency, portability, availability, and renewability
Disadvantages	• Its combustion generates higher NO2 and NO than diesel • It has a higher pour point and cloud point which may cause fuel freezing and difficulty starting in cold weather • Deposits in the combustion chamber

Verma *et al*. [50] study the fuel properties of diesel fuel and several types of biodiesel. The combustion characteristics of B0, B20, B50, and B100 are compared in the Table 6 below. When compared to the other blends, pure diesel has the highest cetane number and density. Pure biodiesel, on the other hand, has a lower heating value than pure diesel blends, implying that more biodiesel will be consumed in the engine to produce the same amount of heat energy. As a result, biodiesel blends like B10, B15, and B20 are far superior as a fuel. The highest heating value and carbon concentration is seen in B0. The higher the carbon concentration, the more CO and CO2 is emitted.

Table 6 Combustion Characteristics of Diesel Blends [50]

Properties	B0 (pure diesel)	B20 (20% biodiesel)	B50 (50% biodiesel)	B100 (pure biodiesel)
Density (kg/m^3)	837.90	842.32	848.95	860.00
Viscosity (cst)	2.64	3.08	3.73	4.82
Higher heating value (MJ/kg)	44.79	43.81	42.35	39.9
Lower heating value (MJ/kg)	41.77	40.86	39.49	37.20
Cetane number	53.30	54.36	55.95	58.60
Air-to-fuel ratio	14.66	14.22	13.56	12.49

2. METHODOLOGY

In this paper, the main sources of information regarding palm oil potential as biofuels were adopted from literature published between year 2000 and 2021. Appropriate previous and current literatures were gathered to identify the most significant viewpoints of palm oil sustainability and its potential as a renewable energy especially in Malaysia. The main focus will be on the Malaysian palm oil biofuels development which consist of prospects, policies, and challenges faced in order to promote biofuels to replace petroleum fuels as most countries in the world are now moving towards a more renewable and sustainable energy.

3. MALAYSIAN PALM OIL BIOFUELS DEVELOPMENT

3.1 Prospects

The oil palm tree thrives in tropical climates with lots of rain, resulting in high biophysical suitability for its growth such as in Malaysia and Indonesia [15], [51]. For the past years, Malaysia is the second largest producer of palm oil accounting for 30%-40% of worldwide demand for crude palm oil (CPO), just behind Indonesia [52]–[57]. However, in term of exporting palm oil, Malaysia is the main and largest supplier of palm oil in the world [27]. Meanwhile, countries such as India, China, Pakistan, Philippines, Bangladesh, Nigeria, USA, and the European Union (EU) are the world major importer of palm oil [58]. Regarding to the biofuels market, Zhou and Thompson [59] stated that it is considered well-established in Brazil, USA, and the European Union. Even though Zaberi and Kusin [60] claimed that the area of oil palm farms in Malaysia is expanding because of the rising global demand for palm oil. This is in agreement with Zentou *et al*. [6], who described that palm oil-based biofuels production is increasing in Malaysia. In addition, Siddique *et al*. [7] stated that alongside Indonesia, Philippines, Thailand, China, and India, Malaysia is among the biggest producers for biofuel in Asia.

In a published article by Loh and Choo [38], the author mentioned that energy securities, agricultural support, and environment are the three primary drivers of biofuels development in Malaysia, with climate change mitigation become the center of focus such as in the effort by European Union and USA in encouraging the use of biofuels. Another vital factor of palm oil to be used as biofuels is it is cost-effective. Othman and Wahab [61] published a paper in which they described that palm oil is the most cost-effective crop when compared to other crops, thus, palm oil could be a viable ecologically acceptable alternative fuel source. Other than that, another study by Lam *et al*. [62] also highlighted that palm oil is the cheapest vegetable oil in the market. In addition, the author also mentioned that apart from being one of the primary raw materials for oleo-chemical industries, palm oil is indeed the world's most cost-effective and environmentally friendly source of food and biodiesel.

For the future, the locals will receive positive social benefits regarding palm oil sectors [63]. Malaysia would be able to create more employment and extra tax revenue for the government, as well as fuel subsidy savings as there will be increasing expansion of palm oil biodiesel production [64]. Kennedy and Ahamad [65] in their study also stated that the country's extensive cultivation of palm oil would result in rapid increase of demand for palm oil-based biofuels. Moreover, proactive approach by the government towards reducing carbon emissions will be influential for Malaysia to achieve its energy independence and green-house gas (GHG) target [62]. Szulczyk *et al*. [66] found that the major contributors of GHG emissions come from transportation, petroleum refining, automobile manufacturing, and electricity generation. With the development of biofuel, agricultural sector will expand and at the same time reduce GHG emissions dependence on fossil fuels in Malaysia by supplying sustainable renewable energy such as the palm oil.

Another significant factor involving prospect of palm oil in Malaysia is the effort from the government to implement biodiesel blend in the transportation industry. One of the early effort was made by the Ministry of Plantation Industries and Commodities of Malaysia which they introduced mixture of 5% processed palm oil and 95% petroleum derived diesel, known as Envo Diesel [57]. As for year 2019, Malaysian government also working on implementing the B10 biodiesel, which is the mixture of 10% processed palm oil and 90% petroleum derived diesel in the transportation sector [38] while the industrial sector is requested to utilize B7 [67] biodiesel which is a blend of 7% palm oil and 93% petroleum derived diesel respectively. The world's biggest palm oil producer, Indonesia, is steps ahead of Malaysia where they are currently working on the B30 palm oil biodiesel in year 2020, and possibly had already researching on higher biodiesel blends, while Malaysia plan to increase its biodiesel mandate from B10 to B20 in the same year [68]. Thus, by the year 2020, it is expected that Malaysia and Indonesia will produce 15000 million tons and 18000 million tons of palm oil respectively to fulfil the increasing demands for palm oil-based products [69].

Apart from the government, academic institutions also have important role in promoting biofuels application in Malaysia. Previous study by Nyakuma [52] indicates that as of year 2017, there are eight academic institutions in Malaysia that are involved in conducting research on biomass potential as listed in Table 7. Considering the number of academic institutions in the country, the number of those that are involved in biomass research are significantly low.

Table 7 Malaysian Academic Institutions Conducting Biomass Research [52]

Institutions	Area of Research
Universiti Kebangsaan Malaysia (UKM)	Jatropha oil extraction, heterogeneous catalysis
Universiti Sains Malaysia (USM)	Heterogeneous catalysis and Biodiesel from Jatropha
Universiti Putra Malaysia (UPM)	Biodiesel/Biofuels Research
Universiti Malaya (UM)	Biomass Conversion, Biodiesel/Biofuels Research
Universiti Teknologi Malaysia (UTM)	Biomass Conversion, Hydrogen, Fuel Processing
Universiti Teknologi Petronas (UTP)	Biodiesel/Biofuels Research

Universiti Islam Antarabangsa Malaysia (UIAM)	Biodiesel/Biofuels Research
Universiti Malaysia Sabah (UMS)	Biodiesel/Biofuels Research

3.2 Malaysian Biofuels Policies

ASEAN countries such as Indonesia, Thailand, Vietnam, the Philippines, Myanmar, Laos, and Cambodia all have their own energy and biofuel policies and targets. In Malaysia, four primary components were used to develop and promote biofuel implementation in diverse sectors, which are the National Biofuel Policy (2006), Malaysian Biofuel Industry Act (2007): Act 666, National Green Technology Policy (2009), and Cabinet Committee on the Competitiveness of Palm Oil [12], [70], [71]. The most common biofuel generated in Malaysia is palm oil-derived biofuels, which are overseen by the National Biofuel Policy [60]. The Malaysian government issued its National Biofuel Policy in March 2006, with the stated goals of reducing reliance on fossil fuels and stabilizing the crude palm oil (CPO) industry through the use of ecologically acceptable and sustainable energy sources [53], [65], [72]. Based on the Malaysia Palm Oil Board's study findings, the policy was developed following comprehensive consultations with all stakeholders [39]. The policy includes a proposal to create B5 blend biodiesel for the domestic market [64], which become the stepping stone for producing biodiesel with higher blending ratio. Moreover, in February 2009, Malaysia implemented the mandate of using B5 palm oil biodiesel in all government vehicles [73], before moving to B10 for the next few years. In Table 8, it can be seen that Indonesia is the most progressive country in targeting to implement high blend of biodiesel (B30) in their vehicles, while Malaysia is only targeting half of that biodiesel blend (B15) in the later year.

Table 8 Current Biodiesel Mandates in Various Countries [34], [74]

Country	Current and Future Biodiesel Mandate
Argentina	B10
Brazil	B8 (2017), B9 (2018), and B10 (2019)
Colombia	B10
Indonesia	B20 (2016) and B30 (2020)
Malaysia	B7 (2016), B10 (2018), and B15 (2021)
Thailand	B5 (2016) and B10 (2018)

The National Biofuel Policy 2006 is intended at reducing Malaysia's reliance on fossil fuels, boosting the use of renewable energy, ensuring the long-term production of palm oil and palm-based biodiesel, and stabilizing the price of palm oil. As can be seen in
Figure **5**, there are five strategic thrusts of the policy which are the Biofuel for Transport, Biofuel for Industry, Biofuel Technologies, Biofuel for Export, and Biofuel for a Cleaner Environment respectively. Furthermore, this policy consists of short-term, medium-term, and long-term scope of implementation as described in Table 9. Zhou and Thomson [59] described that the driving forces behind the policy are dependent on:

a) Energy security
b) Trade balances, foreign exchange, and reducing government expenditure
c) New markets for main agricultural products
d) Employment in the agricultural sector
e) Climate change

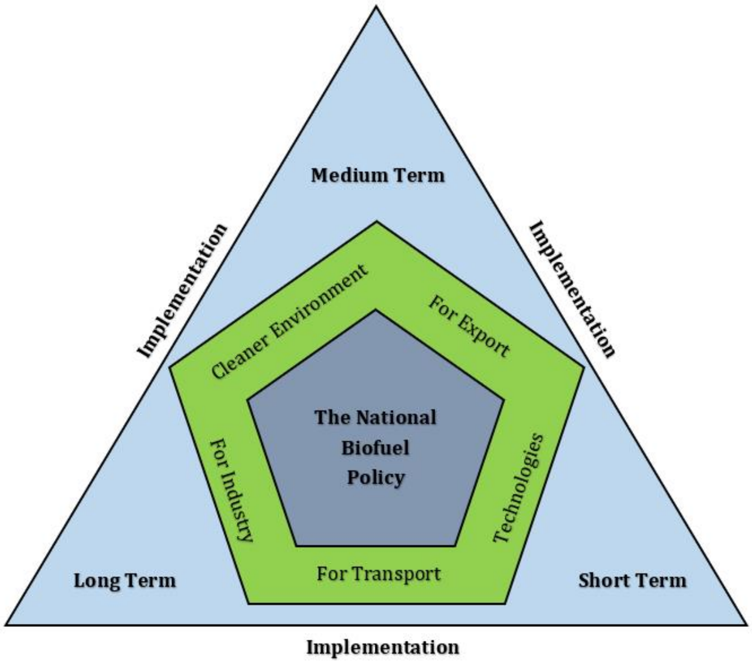

Figure 5. Malaysia Biofuel Policy 2006. [68]–[70]

Furthermore the benefits that are gained from the National Biofuel Policy 2006 are as follows [12], [63], [78]:

- Mitigating the effects of petroleum price scalation
- Savings in foreign exchange
- Environment friendly source of energy
- Mutually beneficial effects on petroleum and palm oil sectors
- Achieving Socio Economic Safety Net
- Efficient utilisation of raw materials
- Reduce dependency on fossil fuels
- Mobilize local resources for biofuel
- Exploit local technology for biofuel production
- Create new demand for palm oil
- Stabilize the CPO price
- Mitigate climate change by reducing greenhouse gas emissions
- Enhance prosperity and well-being of all the stake-holders agriculture and commodity-based industries through stable and remunerative prices

Table 9 Implementation of National Biofuel Policy (reconstructed from Chin, 2011) [78]

Implementation	Description
Short-term	• Establish Malaysian standard specifications for B5 diesel • Participation in B5 diesel trials by selected government departments with their fleets of diesel vehicles • Establish B5 diesel pumps for the public at selected stations • Voluntary trials on B5 diesel by the Malaysian Palm Oil Board (MPOB) for selected users in the industrial sector • Promotional awareness programme to educate the public on the use of B5 diesel
Medium-term	• Establish Malaysian standard specifications for palm oil-based methyl ester biofuel for domestic use and export • Engine manufacturers to extend their warranties to the use of B5 diesel. Extensive B5 diesel testing shall be carried out to facilitate the granting of such engine warranties • Pass and enforce legislation to mandate the use of B5 diesel • Encourage establishment of commercial methyl ester plants. The MPOB will act as a catalyst by pioneering the establishment of palm oil biodiesel plants in Malaysia in collaboration with the private sector
Long-term	• Gradual increase in proportion of processed palm oil in the diesel blend • Greater uptake of biofuels technology by Malaysian companies and foreign companies abroad

Another important catalyst for biofuels production in Malaysia is the Paris Agreement 2016. This agreement is made between several nations as a contribution to strengthen the worldwide response to climate change [79]. In the agreement, the main aims were to minimize the risks and impacts of climate change, as well as improving the ability in reducing GHG emissions and encouraging climate change resilience without jeopardizing global economy and food production. When Malaysia ratified the Paris Agreement in 2016, it promised to cut its GHG emissions by 45% by 2030, by using 2005 as the baseline emissions [66] [55] [80]. Other than that, Malaysia is also involved in the Sustainable Development Goal (SDG) where SDG is responsible to make green energy more affordable and to expand the use of renewable energy while improving energy efficiency and lowering GHG emissions [81]. However, to achieve the goal of sustainable development set by SDG, third and fourth generation feedstocks are the most preferable options. This is because enormous land area is required for cultivation of first and second-generation feedstocks, and this is contrary with SDG's effort to prevent land degradation and protect forest, desert, and mountain ecosystems. Collectively, the progress of significant events of biodiesel industry and policy in Malaysia is described in Table 10.

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Table 10 Significant Events in Malaysian Biodiesel Industry and Policy [68]

Year	Progress
1982	Research at laboratory scale on biodiesel was initiated
1983	Palm Diesel Steering Committee was formed
1984	First biodiesel plant was built
1984-1985	Biodiesel was investigated in taxis
1985	First biodiesel plant was established
1986-1989	Trials phase I started - 31 commercial vehicles and stationary engines
1990	Trials phase II started - test by Mercedes Benz in Germany
1990-1994	Trials phase III started - commercial buses
2001	The use of biodiesel in power plant and research on low-pour-point was initiated
2002	The trial of B2, B5, B10 using liquid palm oil was started
2004	The trial of B5 using refined, bleached and deodorized (RBD) palm oil was started
2005	National Biofuel Policy began to be drafted
2006	National Biofuel Policy was launched First commercialized biodiesel plant started to run Envo Diesel was launched 92 biodiesel licenses were approved
2007	A number of biodiesel projects were cancelled due to higher CPO price
2008	Malaysian Biofuel Industry Act 2007 was implemented Envo Diesel was replaced with B5
2009	The adoption of B5 for government vehicles was initiated
2010	The B5 mandate was postponed to June 2011
2011	The B5 programme began in Putrajaya, Selangor, Kuala Lumpur, Negeri Sembilan and Melaka for transportation and other subsidized sectors
2013	B5 began in Johor for transportation and other subsidized sectors
2013	B5 began in Penang, Kedah, Perak and Perlis for transportation sector
2014	B5 began in Pahang, Kelantan and Terengganu for transportation sector
2014	B7 began in whole peninsular Malaysia for the transportation sector
2015	B7 began in nationwide including Sarawak, Sabah and Labuan for the transportation sector
2018	B10 began in nationwide (by phases) for the transportation sector
2019	B7 began in nationwide (by phases) for industry
2020	Target to use B20 for the transportation sector
2020	Target to use B10 for the industrial sector

3.3 Challenges

In recent years, the sustainability of biofuels has been questioned in relation to food versus fuel trade-offs, carbon accounting, and land use. One of the biggest issues regarding to production of biofuels is the fuel versus food debate [7], [10], [82], especially for the first-generation of biofuels. This because large amounts of edible materials are used to produce these biofuels [81]**.** Apart from that, Araujo *et al*. [10] stressed that another key issue that are circulating the biofuels industry are land and forest destruction. As a result of the growing demand for palm oil, which includes the production of palm oil-derived biofuels as a substitute for fossil fuels to reduce energy consumption and emissions of harmful gases, additional expansion and land conversion to oil palm plantations will take place [60]. Szulczyk and Khan [55] explained that destruction of rainforest will eventually decreases the carbon storage as oil palm trees contain half the carbon as pristine rainforests per hectare. Due to a limitation of ideal land for agriculture expansion to meet global food security demands, less suitable land has been rapidly expanded as being mentioned by Zaberi and Kusin [60] and Jaafar *et al*. [83] where they stated that the conversion of forests and peatlands into oil palm plantations in Malaysia has increased dramatically due to importer countries' demand for biofuels and vegetable oil. Malaysia and Indonesia, which supply 85% of worldwide palm oil [84] through private firms, state-owned enterprises, and smallholders, have become a contested arena for sustainable development and environmental pollution. In addition, the major source of greenhouse gas emissions (GHG), habitat loss, and biodiversity loss has been identified as peatland conversion through drainage [85]–[87]. Drainage in peatlands raises soil oxygen levels, which accelerates decomposition and leads to increased respiration, which triggers GHG emissions. In Malaysia, palm oil plantation is expanding each year. At some point, this situation will interfere with land use for another food source. As a result, the food versus fuel argument may occurs, and issues such as food security versus energy security, food scarcity, and food price increases must be addressed especially by the Malaysian Government.

Other than Malaysia, many countries are turning to biofuels as a more environmentally acceptable alternative to fossil fuels due to worries about energy security, variable fuel prices, and rising greenhouse gas emissions. Legislation mandating the use of biofuels in the energy mix, such as in the United States and the European Union (EU), has boosted demand for vegetable oils for biodiesel production. This growth, while bringing new economic prospects for producer countries, is not without controversy. Chin [78] described that concerns regarding deforestation, biodiversity loss, land conflicts, rivalry with food production, and an increase in carbon emissions from land use change arise as agricultural land is expanded for the development of biofuel feedstock. This situation is similar to that research by Didier [8], where the European Union has been criticized when they introduced a biofuels assistance strategy in 2003, specifically to minimize CO2 emissions in the transportation sector. This is because the policy was seen as the main cause of indirect land use change (ILUC), which escalates worldwide food prices and jeopardizes food security for the poor.

Moreover, critics also claimed that the action by the European Union supports the development of huge land holdings and the usage of available land in emerging countries, and, last but not least, elevates carbon emissions. As the debates on the sustainability of oil palm intensify, it leads to recent action by the European Union to gradually dispose the use of palm oil to make biofuels by the year 2020 as mentioned by Tang and Qahtani [88]. This will directly impact biofuels development in palm oil-producing countries such as Malaysia and Indonesia as one of the largest importers of palm oil is going to reduce the demand of palm oil. In addition to this issue, some European countries has launched the anti-palm oil campaigns, which possibly brings negative impacts on marketability of palm oil products [89]. Apart from the concern on sustainability, the anti-palm oil campaigns were mainly directed to the use of palm oil in food industries, where there is a debate on the nutritional aspects of palm oil that are considered harmful to human’s health. The assessments on the boycott on palm oil are presented in Table 11.

Table 11 Palm Oil Issues in Some European Countries (Reconstructed from Salleh *et al*., 2021) [89]

Country	Anti-Palm Oil Assessment	Main Issue
France	Highly critical	Nutrition and sustainability
Norway	Highly critical	Nutrition and sustainability
Sweden	Highly critical	Nutrition and sustainability
Germany	Critical	NGO activism and media attention
Belgium	Critical	Health and nutrition
Switzerland	Critical	Sustainability
Italy	Critical	Nutrition
United Kingdom	Relatively stable	Sustainability
Netherlands	Relatively stable	Sustainability

Even though Malaysia has unlimited sources of palm oil, expected rate of biofuel production is still could not be met due to the minimal demand for biofuel, causing no large-scale bioethanol and biomethanol production has begun in this country [25]. Another challenge faced in order to implement biofuel application in this country is the cost involved. The cost of biofuel production also has a significant impact on the biofuel's long-term viability. The cost of producing biofuel includes the cost of the feedstock, the cost of processing, and the cost of capital [81]. However, many studies have found that renewable energy is more expensive than fossil fuels. Biodiesel, for example, diverts oil away from human and animal consumption, and biodiesel cannot compete with fossil fuels unless the government subsidizes it [66].

Another challenge encountered by Malaysia in developing biofuel product is the lack of research regarding to biofuel potentials in this country. As been mentioned in the previous section, only eight academic institutions in Malaysia that are involved in conducting research on biomass potential as of the year 2018 [52]. Despite their key roles as the world's first and second largest producers of palm oil biodiesel, Indonesia and Malaysia do not contribute much to published biodiesel patents. It is China, as shown in
Figure **6**, that contributes the greatest to the total number of patents published, followed by the World Intellectual Property (WIP) Organization and the USA with totals of 647, 343 and 266 patents, respectively [7]. These three categories account for approximately 75% of the overall patents. This finding suggests a promising future for the biodiesel business in China, while also pointing to a dearth of biodiesel research and development in Indonesia and Malaysia, despite their status as the world's major palm oil producers. [68].

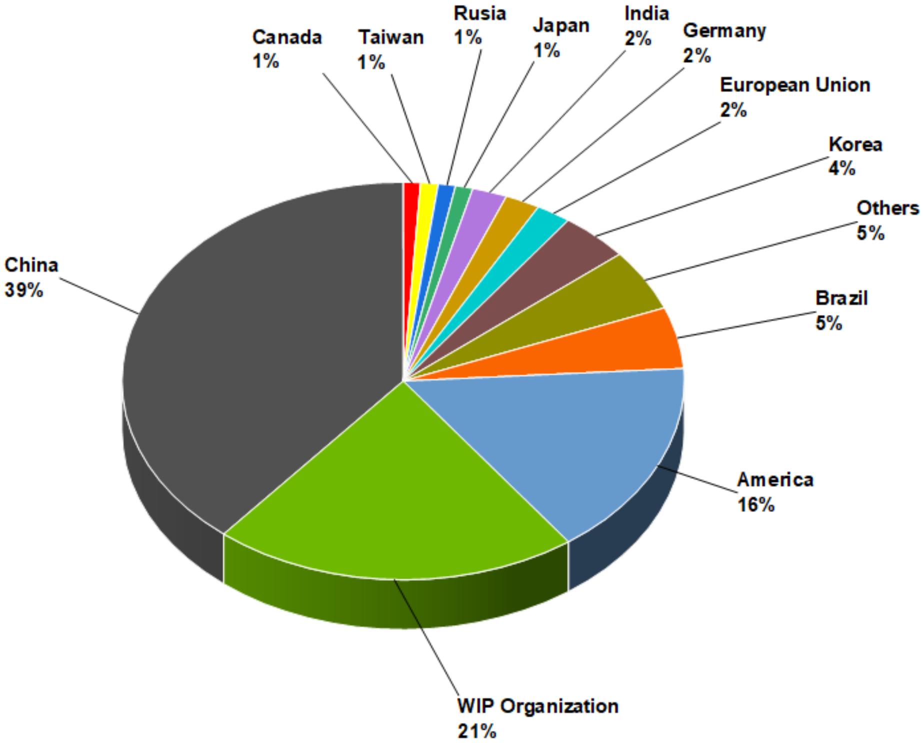

Figure 6. Published patents on biodiesel production from the year 1999-2018 (Reconstructed from Mahlia *et al*., 2020). [90]

As can be observed in

Figure **7** (a), Malaysia is the third-largest consumer of energy among the seven ASEAN countries. in

Figure **7** (b), by the year 2035, Malaysia also projected to be the third-largest consumer of energy that is related to CO2 emissions. Meanwhile in

Figure **7** (c), the demand for energy in the form of oil is expected to be highest for transportation sector in the year 2035. These statistics reflect that in the future, most ASEAN countries will need more energy and the oil or fuel supply especially for transportation sector need to be monitored closely as fossil fuel sources around the world are depleting rapidly.

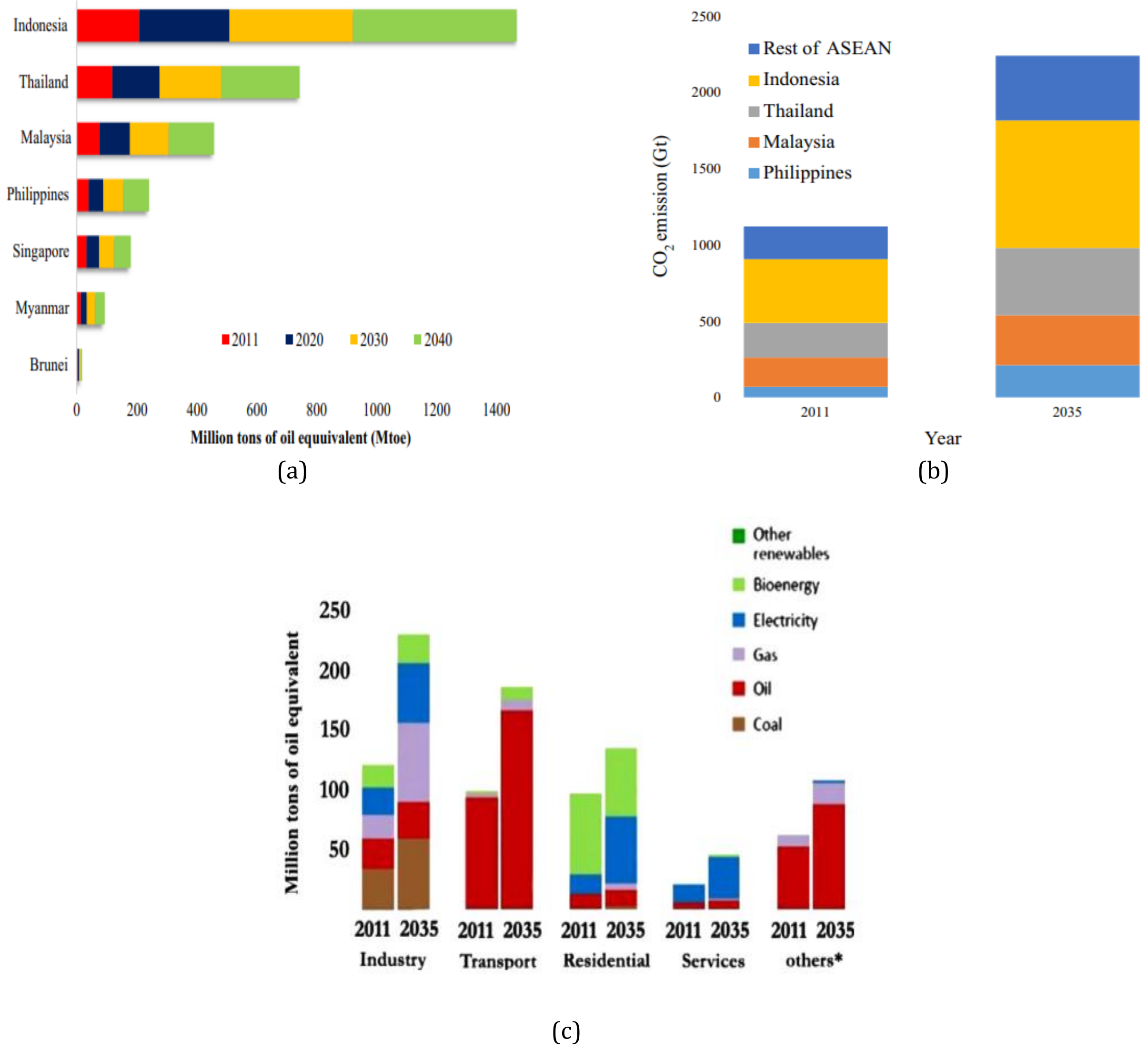

Figure 7. (a) ASEAN primary energy consumption (2011–2040) (b) Energy related CO2 emission of ASEAN (c) ASEAN energy demand by sector. [12]

4. CONCLUSION

In term of sustainability, biofuels remain in a pivotal position especially for the transportation sector. As for Malaysia, palm oil biodiesel is still the most popular renewable energy compared to other types of biofuels. This is because the statistics from this study indicate that the production and demand for palm oil is increasing each year. However, the government is continuously observing and controlling the palm oil plantation expansion in Malaysia in order to avoid inappropriate deforestation activities, and at the same time trying to improve the palm oil biofuel production. At the moment, the country's existing biodiesel blends for the transport sector are the B5 and B10. Meanwhile, for industrial sector the current available biodiesel blend for the industrial sector is the B7. Through palm oil cultivation, the production of palm oil biodiesel has assisted the nation in minimizing dependency in fossil fuels. Furthermore, the policies and mandates stipulated by the Malaysian government has help the country to achieve its target which is mainly to reduce the GHG emissions for at least 1.6 million tons annually. Moreover, the increasing global demand and production rate for palm oil will result in palm oil plantation expansion, which provide wide variety of social and economic benefits, but also creating issues such as deforestation and food security. Thus, the government must stabilize the benefits and drawbacks of cultivation of palm oil through the existing policies in order for the country to achieve its main target to reduce GHG emissions in the long run without neglecting the element of sustainability.

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