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Navigating the Transition: Biodiesel Development and Challenges in Malaysia's Energy Landscape

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ABSTRACT: Overdependence on fossil fuels impacts the environment, economy, and society. The crude oil price increases when the supply of fossil fuels is insufficient, leading to economic recessions. The development of biodiesel has replaced fossil fuels in the transportation sector and is pending use in the industrial sector. It has brought various advantages to the economy, society, and environment. However, the development of biodiesel is still facing some challenges, such as labor shortages, the price of feedstock, environmental debates, and the adoption of biodiesel for the transportation sector. The introduction of the National Biofuel Policy and the Biofuel Industry Act 2007 has encouraged the use and development of biodiesel. Biodiesel technologies such as Envo Diesel, B5 biodiesel, B7 biodiesel, and B10 biodiesel were developed based on research done by the Malaysian Palm Oil Board (MPOB).

KEYWORDS: Biodiesel; challenge of biodiesel; prospect of biodiesel, Malaysia

1. Introduction

The overdependence on fossil fuels has caused several issues to the world such as the increase in oil prices, the energy security due to depletion of fossil fuels and the environmental concerns rise. Fossil fuels are important as they can burn to produce energy for transportation, industrialization and promote the development of economy. However, they also pollute the environment through emitting greenhouse gases. Therefore, biodiesel becomes an advanced renewable energy to replace the fossil fuels. Biodiesel production from palm oil is the one of the Malaysia’s economy sources. The began of biodiesel production has reduced the reliance on fossil fuel and provided a sustainable energy supply in transportation sector. The biodiesel is believed to be the most potential renewable sources in the future as it has gradually replaced the position of petroleum diesel in the world. The efforts done by the government and MPOB has introduced different types of biodiesel technology in 2006 to 2019. The National Biofuel Policy (NBP) was introduced to encourage the uses of biodiesel in Malaysia [1].

Envo Diesel was developed in 2006 and replaced by B5 biodiesel in 2008 as it has failed in the market [2]. The B5 biodiesel was replaced by B7 biodiesel after its mandate has been fully implemented in nationwide. The higher biodiesel production was expected during the implementation of B7 biodiesel in 2015 and it was replaced by B10 biodiesel in 2018. During the development of biodiesel, various challenges such as the labour shortage, price of feedstock, environment debate and adoption of biodiesel for transportation sector have been faced.

2. Current Status of Biodiesel in Malaysia

Malaysia is a palm-oil based biodiesel country and is the second larger palm oil producer in the world which currently having about 28% of the palm oil production and 33% of the world exports (Malaysian Palm Oil Council, n.d.). The demand for palm oil has been increased due to its wide variety of uses. Such that the usage of palm oil as the primary feedstock of the production of biodiesel is well-known. It is the best feedstock to produce biodiesel as its prices is the lowest among other oil crops and has distinct advantages over other oil crops [3]. Malaysia has recognized the importance of the biodiesels as it provides various benefits and has less harmful effects on the environment. As shown in Table 2, the palm oil acts as a renewable source has the highest average oil yield with compared to other oil crops and the utilization of palm oil also helped to reduce the dependency on fossil fuels and increased the energy security [4].

The Government of Malaysia (GOM) has invested the palm oil research which encouraged has encouraged the development of palm biodiesel through the MPOB [3]. The extensive research and technological development on the production of palm biodiesel have been successfully carried out by MPOB with the cooperation from the local oil giant "Petronas" [5]. The research and development (R&D) have assisted the government to establish the nation' biofuels strategy [2]. Based on the study above, the NBP has been released by GOM in 2006 to ensure the uses of alternative energy sources are environmental-friendly which also reduced the dependency on fossil fuels, and stabilized the prices for palm oil [1]. However, the implementation of the policy has been postponed to 2008 due to the high prices of oil palm. The policy has accounted in the development, feasible use and sustainable supply of biofuels in short, medium and long terms as shown in Figure 1 [3, 1].

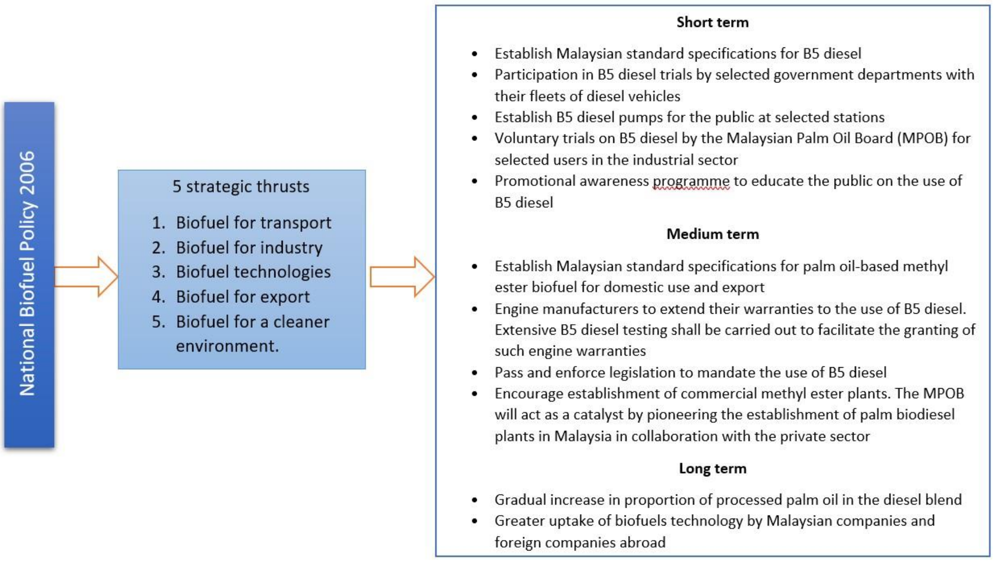

Figure 1. The national biofuel policy.

Other than that, GOM has also established the Biofuel Industry Act 2007 (BIA) to complement the NBP. The act was enforced in 2008 to regulate and facilitate the development of biodiesel industry in Malaysia. Due to the enforcement of act, the licensing process has been simplified and the manufacturing companies only need to apply for one license which convenience the companies [6] and the activities licenses under the act has been recorder under Table 1 [6]. Besides, Malaysia has exported RM 77.8 billion for palm oil and palm-related products in 2017. It clearly shows that oil plantation activity in Malaysia is an upward trend [7]. The palm oil industry in Malaysia has represented the fourth largest contributor under the 12 National Key Economic Areas (NKEA) which significantly increase the country's gross domestic product (GDP) and create more job opportunity. The development of industry and enhancement of product quality have caused the NKEA to exceed its 2020 target. The target of 110,844 hectares for the oil palm plantation and replantation has been exceeded with 126,290 hectares [7]. Due to the activities above, the crude palm oil (CPO) price in 2017 has been noticed that it was comparably higher than in 2016. Such that the CPO price in 2017 was fluctuated between a range of RM 2,300 to RM 3,300 while the CPO price in 2016 was fluctuated between a range of RM 2,257 to RM 3,200. Other than that, the fresh fruit brunch (FBB) harvesting has increased by 18% of 86.33 million tonnes in 2016 to 101.74 million tonnes in 2017 [7]. Table 3 has shown the biodiesel production during 2016 to 2019 [8].

Table 1. The activity licenses under the Biofuel Industry Act 2007 [6].

Activity License	
Production of biofuel	• Construction of any biofuel plant or biofuel blending plant • Production of any biofuel • Blending of any biofuel with any other fuel or biofuel
Trading of biofuel	• Export, import, transport and/or storage of any biofuel, biofuel blended with any other fuel or biofuel blended with any other biofuel
Biofuel services	• Survey or testing of any biofuel, biofuel blended with any other fuel or biofuel blended with any other biofuel

Table 2. Oil crop productivity for major oil crop.

Oil Crop	Oil production (million tons)	Total production (%)	Average oil yield (tons/ha/year)	Planted area (million ha)	Total area (%)
Soybean	33.58	31.69	0.36	92.10	42.24
Sunflower	9.66	9.12	0.42	22.90	10.50
Rapeseed	16.21	15.30	0.59	27.30	12.52
Palm oil	33.73	31.84	3.68	9.17	4.21
Others	12.76	12.04	-	66.55	30.52
Total	105.94	100	-	218.02	100

The chronology of biodiesel development in Malaysia has been listed in Table 3 [3]. In the early 1980s, the laboratory research on palm methyl eaters have began and several trials have been done to ensure the production of palm biodiesel were viable to work in diesel engines. The first biodiesel named "Envo Diesel" has been introduced by the Ministry of Plantation Industries and Commodities of Malaysia (MPIC) during the establishment of NBP in 2006 [2]. However, the Envo Diesel has failed in the market and was aborted by the government in 2008. In the same year, the B5 biodiesel has been introduced to replace the Envo Diesel. The implementation of B5 mandate was successful as it has been executed to nationwide. The success of B5 mandate has encouraged the B7 biodiesel to begin sell in 2015. The B10 mandate has been promoted in 2019 after the postponed in 2016.

Table 3. Statistics of Malaysian biodiesel production and exports during 2016 to 2019.

Year	*Biodiesel (Million Litters)*			
	2016	**2017**	**2018**	**2019**
Beginning stocks	0	0	0	0
Production	730	917	1,245	1,690
Imports	0	0	0	0
Exports	94	267	585	750
Consumption	636	650	660	940
Ending Stocks	0	0	0	0

3. Challenges

The development of biodiesel in Malaysia is still facing various challenges although Malaysia has encouraged the uses of palm biodiesel among the citizens.

3.1. Labour shortage.

The oil palm plantation sector has been facing labor shortages from the past until now. The labor shortage may be due to several reasons, such as Malaysia's high dependence on foreign workers or the lack of interest among local workforces in this sector, despite many employment opportunities. Historically, Malaysia has heavily relied on foreign labor from countries such as Indonesia, the Philippines, India, and others. For instance, only 83,000 out of 450,000 workers were local, with the remaining foreign labor mostly from Indonesia [9]. The implementation of policies by the GOM has encouraged economic development, resulting in a demand for workers that has exceeded supply [10]. Consequently, an influx of foreign workers has been attracted to the country due to the rising demand for labor, which has contributed to the country's development. This influx created new employment opportunities in various sectors such as construction, services, and manufacturing. As a result, the agricultural sector, including oil palm plantations, continued to face labor shortages, further promoting the entry of foreign laborers [11].

The government has also attempted to reduce dependency on foreign workers by encouraging local participation in the plantation sector. However, most locals are not interested in working in plantations, often choosing the agricultural sector as their third choice after manufacturing and retail [12, 9]. Consequently, there is a lack of young people entering the agricultural sector due to negative perceptions about it. It was estimated that the labor shortage in 2016 was about 39,000 workers, most of whom were needed for harvesting fresh fruit bunches (FFB) and collection activities [11]. The labor shortage in the agricultural sector, especially in oil palm plantations, could cause a loss of income ranging from RM 2.8 billion to RM 3.9 billion [11].

The palm oil industry is considered one of the most important contributors to Malaysia’s economy. Oil palm is used as feedstock for biodiesel production. However, the heavy reliance on biodiesel production drives up the price of CPO as demand increases. Consequently, the production of biodiesel becomes economically unfeasible. Additionally, biodiesel cannot compete with petroleum diesel, which is subsidized by the government [3]. For example, the GOM provided RM 23.5 billion in fuel subsidies in 2009 [13].

Thus, high CPO prices reduce biodiesel production. Furthermore, heavy dependence on oil palm as the sole feedstock prevents large-scale biodiesel production. Oil palm plantations require large land areas, leading to deforestation. Therefore, Malaysia’s biodiesel industry faces the challenge of shifting from single feedstock to multiple feedstocks for biodiesel production [14]. The low exports of biodiesel between 2010 and 2012, shown in Table 4, reflect this issue. The fluctuation of CPO prices is influenced by various factors, including the demand and supply of palm oil, the price of other raw materials, and environmental factors affecting oil palm plantations.

Table 4. Statistics of Malaysian biodiesel production and exports during 2006 to 2015.

	Biodiesel (Million Litters)									
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Beginning stocks	0	0	0	0	0	0	0	0	0	0
Production	353	434	521	241	130	204	271	507	611	660
Imports	122	144	141	0	0	0	0	0	0	0
Exports	345	527	630	246	97	54	31	192	95	204
Consumption	130	52	10	0	33	150	240	315	516	456
Ending Stocks	0	0	0	0	0	0	0	0	0	0

3.2. Environment debate.

The expansion of oil palm plantations has subjected Malaysia to a series of ecological impacts. Deforestation occurred as the expansion of oil palm plantations required large areas of peatlands. The conversion of pristine forest to oil palm plantations in Peninsular Malaysia increased from 1.7 Mha to 2.7 Mha during the period from 1990 to 2010, which is approximately 20% of the area in Peninsular Malaysia [15]. Due to the oil palm plantations, only 23% to 27% of bird species richness was retained [16]. The high emissions of nitrogen oxides and volatile organic compounds caused by the plantations resulted in secondary pollutants, also known as ground-level ozone [17]. Ground-level ozone has significant effects on human health and vegetation. The leaching of fertilizer from the plantations into nearby water resources also led to eutrophication [18].

3.3. Adoption of biodiesel in transportation sector.

The lack of government support can create barriers to the adoption of biodiesel in the transportation sector. In 2006, the GOM established the NBP to encourage the use and production of biodiesel. Through this implementation, oil palm plantations were promoted since oil palm is used as the raw material for biodiesel production. However, the policy was not effective because the government subsidized petroleum diesel, leading to uneven competition for biodiesel [2]. The lack of subsidies for biodiesel demotivated companies from adopting green practices [19]. Additionally, the lack of environmental-commercial benefits has also discouraged the adoption of biodiesel. Transport companies are unlikely to adopt green practices if there is no benefit to be gained from them [20]. These companies may prefer to use fossil fuels rather than adopting biodiesel in transportation services to ensure low-cost operations [21]. Furthermore, environmental issues resulting from oil palm plantations have detrimental effects, including deforestation, biodiversity loss, water pollution, and soil erosion [22].

3.3. Sustainability of palm oil as a feedstock.

The sustainability of palm oil as a feedstock for biodiesel is a contentious issue with significant environmental, economic, and social implications. While palm oil is favored for its high oil yield and cost-effectiveness, its cultivation often leads to deforestation, habitat loss, and increased greenhouse gas emissions, undermining global carbon sinks and biodiversity [23]. Additionally, the expansion of palm oil plantations can result in land disputes and the displacement of indigenous communities, raising concerns about social equity and land rights [24]. Efforts to promote sustainable practices include certification schemes like the Roundtable on Sustainable Palm Oil (RSPO), which aim to encourage environmentally friendly cultivation and fair labor practices. However, the effectiveness and enforcement of these certifications are often debated [25]. Economic sustainability is also a challenge, as reliance on palm oil can lead to vulnerability due to price volatility. Diversifying feedstock sources and investing in research for alternative biofuels are essential for mitigating risks [26]. In summary, the sustainability of palm oil for biodiesel in Malaysia requires a delicate balance between economic benefits, environmental protection, and social equity, necessitating comprehensive policies and ongoing innovation in agricultural practices.

4. Biodiesel Technology

Based on research, the transesterification process is used to reduce the viscosity of feedstock to produce substances closer to conventional fossil-based diesel oil [27]. Methyl esters derived from palm oil through the transesterification process are a key product of palm biodiesel manufacturing, as shown in Figure 2 [28]. These substances may need further modification or none at all to be used in diesel engines [28].

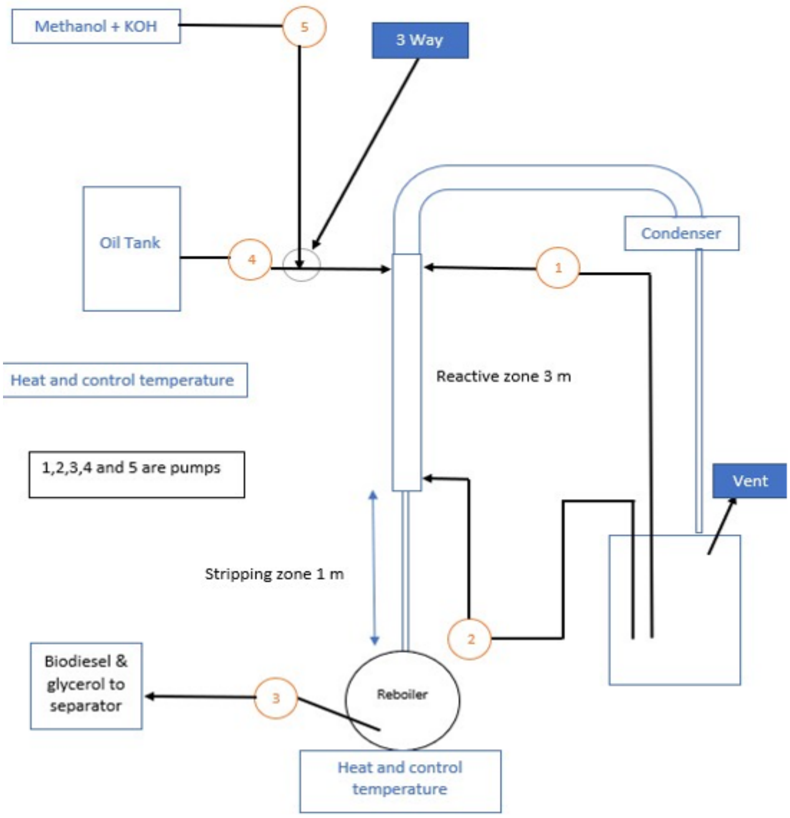

Figure 2. Transesterification process of palm oil.

4.1. Envo Diesel.

The NBP policy and BIA Act were established based on research findings by MPOB. Launched in March 2006, these initiatives were underpinned by five strategic thrusts. Envo Diesel was MPOB's brand name for a blend of 5% processed palm oil and 95% petroleum diesel [29]. However, the introduction of Envo Diesel was not successful due to obstacles from automobile manufacturers, specifically the Japan Automobile Manufacturers Association (JAMA), which refused to extend engine warranties because Envo Diesel's characteristics were incompatible with their engines [14]. For instance, blended biodiesel has a higher possibility of solidifying at lower temperatures, making it unsuitable for cold and temperate conditions [14]. Additionally, high CPO prices affected investor confidence in the biodiesel industry, making the program economically unfeasible and causing some biodiesel plants to shut down or decrease their output [2]. Consequently, the government aborted the Envo Diesel program in 2008.

4.2.B5 Biodiesel.

As the Envo Diesel has failed to achieve the aim of NBP policy, a bend of 5% palm methyl esters and 95% of petroleum diesel has replaced it in the same year [30]. The B5 biodiesel started to launch in 2009. The implementation of B5 biodiesel has been divided into three phases. The first phase was implemented in 2009 with the participation of government agencies. The first phase has been implemented for 3 years with the involvement of diesel engine vehicle from the agencies such as Kuala Lumpur City Council (DBKL) and Armed Forces [31] The implementation has increased the biodiesel production by 48% in 2011 to 173,220 tonnes of palm biodiesel from 117,173 tonnes of palm biodiesel in 2010 [31]. In tandem with the success of first phase, second phase has been implemented by widening the B5 program in the retail stations of the Central Region [1]. It showed that the implementation of B5 program in the Central Region was successful due to the high usage of B5. The final phase is to implement the B5 program in nationwide. Sabah, Sarawak, and the Federal Territory of Labuan have been implemented with the B5 program. In the same year, the government has announced the use of B7 biodiesel to replace B5 biodiesel.

4.3. B7 biodiesel.

In tandem with the increase of CPO supply and decrease of CPO price, the government has decided to launch B7 biodiesel mandate in 2015 [32]. The B7 biodiesel is the blending of 7% palm methyl esters and 93% petroleum diesel. During the implementation, the biodiesel production was expected to produce 537 million litters annually. Whereby, the biodiesel production has exceeded its expectation which in 2015, 2016, 2017, and 2018, the production were 660 million litters, 730 million litters, 917 million litters, and 1,245 million litters respectively. The production of biodiesel has been shown in Table 3 and 4. Whereas, MPOB has stated that the implementation of B7 biodiesel has reduced about 1.05 million tons of greenhouse gas per year which has achieved the aims of NBP policy [32].

4.4.Advancements in alternative strategies for biodiesel production.

In the realm of biodiesel technology, several novel alternative strategies are emerging to enhance efficiency and sustainability. Algae-based biodiesel stands out for its ability to convert sunlight and CO_2 into lipids, offering higher yields compared to traditional crops and utilizing non-arable land [33]. Microbial biodiesel production involves leveraging microbes like yeasts and bacteria to produce lipid-rich biomass through genetic engineering, optimizing lipid profiles for biodiesel quality [34]. Waste cooking oils and animal fats provide another sustainable feedstock, reducing waste disposal issues while ensuring a reliable source for biodiesel production [35]. Catalytic and non-catalytic transesterification methods are evolving, with advancements in solid acid catalysts and enzymatic processes reducing energy consumption and improving reaction efficiency [36]. Thermochemical conversion techniques like pyrolysis and hydrothermal liquefaction convert biomass into bio-oils suitable for biodiesel refining, offering versatile solutions for various feedstocks [37]. Hybrid approaches integrate different feedstocks or production methods to maximize yield and sustainability, exemplifying integrated biorefinery concepts [38]. Lastly, CO_2 utilization for biodiesel production underscores efforts towards carbon neutrality by incorporating carbon dioxide into biofuel production processes [39]. These strategies collectively represent a diverse and innovative landscape aimed at advancing biodiesel technology towards greater environmental and economic sustainability.

5. Advantage of biodiesel

The advantage of biodiesel will be the reduce of greenhouse gas emission. Based on the research from MPOB, the greenhouse gas emissions of B7 biodiesel has reduced about 1.05 million tons per year [32]. The advantage of using biodiesel also help to lower the reliance on fossil fuel [40]. Besides, the biodiesel acts as a renewable fuel is sustainable and environmental-friendly. Other than that, the biodiesel has higher combustion efficiency [41]. Additionally, biodiesel is a local product which makes it more affordable than diesel [40]. It is non-toxic and biodegradable and also has higher flash point which is safe to use in transport and storage [41]. The production of biodiesel is environmental-friendly and achieve the goals of NBP policy to reduce the reliance on fossil fuels. The development of biodiesel technology can help to reduce the emission of greenhouse gas to the atmosphere [42]. The emission of biodiesel is safer for people to breathe. However, the advantages of biodiesel cannot be neglected the environmental impacts that may occur. Therefore, there are several considerations needed to take in count. The conversion of oil palm plantation from forest is associated with the deforestation activity. This has led to the loss of biodiversity and pollution to the environment. The habitat loss due to the deforestation has threaten the biodiversity in Malaysia [43]. The expansion of land has result in the loss of local species such that the bird species richness has retained only 23% and 27% [18]. The soil erosion may also occur during the conversion [22]. The uses of pesticide and fertilizer in the plantation will cause the pollution to the water. The runoff of nitrogen into the nearby stream may cause eutrophication which indirectly cause the death of aquatic life [44].

6. Conclusion

In conclusion, biodiesel technology in Malaysia is on the rise, boosting the economy and curbing greenhouse gas emissions. Challenges such as labor shortages, feedstock prices, environmental concerns, and biodiesel adoption in transportation hinder its development. Efforts by the GOM and MPOB have led to increased biodiesel production and exports. However, heavy reliance on palm oil limits large-scale production. Therefore, Malaysia should transition from single feedstock to multi feedstock sources to diversify supply and ensure sustainable biodiesel production.

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Competing Interest

All the authors declared no conflict of interest.

References

[1] Mohd Yusoff, M.H.; Abdullah, A.Z.; Sultana, S.; Ahmad, M. (2013). Prospects and current status of B5 biodiesel implementation in Malaysia. *Energy Policy*. *62,* 456–462. http://doi.org/10.1016/j.enpol.2013.08.009.

[2] Johari, A.; Nyakuma, B.B.; Nor, S.H.M.; Mat, R.; Hashim, H.; Ahmad, A.; Abdullah, T.A.T. (2015). The challenges and prospects of palm oil based biodiesel in Malaysia. *Energy*, *81*, 255–261. http://doi.org/10.1016/j.energy.2014.12.037.

[3] Biofuels in Malaysia. (accessed on 2 April 2023) Available online: https://www.cifor-icraf.org/knowledge/publication/3470/.

[4] Basiron, Y. (2007). Palm oil production through sustainable plantations. *European Journal of Lipid Science and Technology*, *109*(4), 289–295. https://doi.org/10.1002/ejlt.200600223.

[5] Kalam, M. A.; Masjuki, H. H. (2005). Recent developments on biodiesel in Malaysia. *Journal of Scientific & Industrial Research*, *64*(11), 920–927.

[6] Malaysian Biofuel Industry Act 2007. (accessed on 2 April 2023) Available online:https://www.iea.org/policies/5792-malaysian-biofuel-industry-act-2007

[7] National Transformation Programme Annual Report 2017. (accessed on 2 April 2023) Available online: http://www.myrekatech.com/main/medias/NTP_AR2017_ENG.pdf.

[8] Malaysia Biofuels Annual Report 2019. (accessed on 2 April 2023) Available online: https://fas.usda.gov/data/malaysia-biofuels-annual-2.

[9] Labour Markets. (accessed on 2 April 2023) Available online: https://open.dosm.gov.my/dashboard/labour-market.

[10] Foreign labour boost to help palm oil production this year. (accessed on 22 July 2024) Available online: https://www.nst.com.my/business/economy/2024/07/1074927/foreign-labour-boost-%C2%A0help-palm-oil-production-year.

[11] Ismail, A. (2013). The effect of labour shortage in the supply and demand of palm oil in Malaysia. *Oil Palm Industry Economic Journal*, *13*(2), 15–26.

[12] Mohammad Amizi, A.; Abdullah, N.; Alic, J. (2016). Perception of local youths in Malaysia East Coast Region towards the career prospect in oil palm plantation. *Asia Pacific Journal of Advanced Business and Social Studies*, *2*(2), 685–693.

[13] Hakim, R.A.; Ismail, R.; Razak, N.A.A. (2014). Fuel subsidy rationalisation: The perils of the middle class in Malaysia. *Jurnal Ekonomi Malaysia*, *48*(2), 83–97. https://doi.org/10.17576/jem-2014-4802-08.

[14] Lim, S.; Teong, L.K. (2010). Recent trends, opportunities and challenges of biodiesel in Malaysia: An overview. *Renewable and Sustainable Energy Reviews*, *14*(3), 938–954. https://doi.org/10.1016/j.rser.2009.10.027.

[15] Gunarso, P.; Hartoyo, M.E.; Agus, F.; Killeen, T.J. (2013). Oil palm and land use change in Indonesia, Malaysia and Papua New Guinea. Technical Panels of the 2nd greenhouse gas working Group of the Roundtable on Sustainable Palm Oil (RSPO), 29-63.

[16] Peh, K.S.H.; de Jong, J.; Sodhi, N.S.; Lim, S.L.H.; Yap, C.A.M. (2005). Lowland rainforest avifauna and human disturbance: Persistence of primary forest birds in selectively logged forests and mixed-rural habitats of southern Peninsular Malaysia. *Biological Conservation*, *123*(4), 489–505. https://doi.org/10.1016/j.biocon.2005.01.010.

[17] Hewitt, C.N. (2009). Nitrogen management is essential to prevent tropical oil palm plantations from causing ground-level ozone pollution. *Proceedings of the National Academy of Sciences*, *106*(44), 18447–18451. https://doi.org/10.1073/pnas.0907541106.

[18] Tang, K.D.; Qahtani, H.M. (2019). Sustainability of oil palm plantations in Malaysia. *Environment, Development and Sustainability*, 1–25. https://doi.org/10.1007/s10668-019-00458-6.

[19] Abdullah, M.; Zailani, S.; Iranmanesh, M.; Jayaraman, K. (2016). Barriers to green innovation initiatives among manufacturers: the Malaysian case. *Review of Managerial Science*, *10*(4), 683–709. https://doi.org/10.1007/s11846-015-0173-9.

[20] Hemel, C.V.; Cramer, J. (2022). Barriers and stimuli for ecodesign in SMEs. *Journal of Cleaner Production*, *10*(5), 439–453. https://doi.org/10.1016/S0959-6526(02)00013-6.

[21] Zailani, S.; Iranmanesh, M.; Sean Hyun, S.; Ali, M. H. (2019). Barriers of biodiesel adoption by transportation companies: A case of Malaysian transportation industry. *Sustainability*, *11*(3), 931. https://doi.org/10.3390/su11030931.

[22] NEPCon. (2017). Palm Oil Risk Assessment Malaysia-Peninsular. NEPCon. https://www.nepcon.org/sites/default/files/library/2017-11/NEPCon-PALMOIL-Malaysia-Peninsular-Risk-Assessment-EN-V2_0.pdf.

[23] Deforestation fronts: Drivers and responses in a changing world. WWF. (accessed on 2 April 2023) Available online: https://www.worldwildlife.org/publications/deforestation-fronts-drivers-and-responses-in-a-changing-world-summary.

[24] Oil palm expansion in South East Asia: Trends and implications for local communities and indigenous peoples. Forest Peoples Programme. (accessed on 2 April 2023) Available online: https://www.recoftc.org/publications/0000117.

[25] Bezuidenhout, H.; Mhonyera, G.; Van Rensburg, J.; Sheng, H.H.; Carrera, J.M., Jr.; Cui, X. (2021). Emerging Market Global Players: The Case of Brazil, China and South Africa. *Sustainability*, *13*, 12234. https://doi.org/10.3390/su132112234.

[26] Lam, M. K.; Lee, K. T.; Mohamed, A. R. (2009). Life-cycle assessment for the production of biodiesel: A case study in Malaysia for palm oil versus jatropha oil. *Biofuels, Bioproducts and Biorefining*, *3*(6), 601–612. https://doi.org/10.1002/bbb.182.

[27] Zahan, K.A.; Kano, M. (2018). Biodiesel production from palm oil, its by-products, and mill effluent: a review. *Energies*, *11*(8), 2132. https://doi.org/10.3390/en11082132.

[28] Prasertsit, K.; Mueanmas, C.; Tongurai, C. (2013). Transesterification of palm oil with methanol in a reactive distillation column. *Chemical Engineering and Processing: Process Intensification*, *70*, 21–26. https://doi.org/10.1016/j.cep.2013.05.011.

[29] Malaysian Palm Oil Industry Has A Long-Term Plan to Address EU Regulation. (accessed on 2 April 2023) Available online: http://mpoc.org.my/malaysian-palm-oil-industry./.

[30] Masjuki, H.H.; Kalam, M.A.; Mofijur, M.; Shahabuddin, M. (2013). Biofuel: policy, standardization and recommendation for sustainable future energy supply. *Energy Procedia*, *42*, 577–586. https://doi.org/10.1016/j.egypro.2013.11.059.

[31] Yusoff, M.H.M.; Abdullah, A.Z.; Sultana, S.; Ahmad, M. (2013). Prospects and current status of B5 biodiesel implementation in Malaysia. *Energy Policy*, *62*, 456–462. https://doi.org/10.1016/j.enpol.2013.08.009

[32] Biofuels Annual Report 2014 Malaysia. (accessed on 2 April 2023) Available online: https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Biofuels%20Annual_Kuala%20Lumpur_Malaysia_6-25-2014.pdf.

[33] Neeti, K.; Gaurav, K.; Singh, R. (2023). The Potential of Algae Biofuel as a Renewable and Sustainable Bioresource. *Engineering Proceedings*, *37*, 22. https://doi.org/10.3390/ECP2023-14716.

[34] Sundarsingh Tensingh, J.A.; Shankar, V. Enhancing the Biodiesel Production by Improving the Yield of Lipids in Wild Strain by Inducing Nitrogen Ion Mutation in *Rhodotorula mucilaginosa*. *Microbiology Research*, *14*, 1413–1426. https://doi.org/10.3390/microbiolres14030096.

[35] Cerón Ferrusca, M.; Romero, R.; Martínez, S.L.; Ramírez-Serrano, A.; Natividad, R. (2023). Biodiesel Production from Waste Cooking Oil: A Perspective on Catalytic Processes. *Processes*, *11*, 1952. https://doi.org/10.3390/pr11071952.

[36] Farouk, S.M.; Tayeb, A.M.; Abdel-Hamid, S.M.S.; Osman, R.M. (2024). Recent advances in transesterification for sustainable biodiesel production, challenges, and prospects: a comprehensive review. *Environmental Science and Pollution Research*, *31*, 12722–12747. https://doi.org/10.1007/s11356-024-32027-4.

[37] Jha, S.; Nanda, S.; Acharya, B.; Dalai, A.K. (2022). A Review of Thermochemical Conversion of Waste Biomass to Biofuels. *Energies*, *15*, 6352. https://doi.org/10.3390/en15176352.

[38] Neupane, D. (2023). Biofuels from Renewable Sources, a Potential Option for Biodiesel Production. *Bioengineering*, *10*, 29. https://doi.org/10.3390/bioengineering10010029.

[39] Khan, N.; Sudhakar, K.; Mamat, R. (2021). Role of Biofuels in Energy Transition, Green Economy and Carbon Neutrality. *Sustainability*, 13, 12374. https://doi.org/10.3390/su132212374.

[40] Meher, L.C.; Sagar, D.V.; Naik, S.N. (2006). Technical aspects of biodiesel production by transesterification-a review. *Renewable and Sustainable Energy Reviews*, *10*(3), 248–268. https://doi.org/10.1016/j.rser.2004.09.002.

[41] Hassan, M.H.; Kalam, M.A. (2013). An overview of biofuel as a renewable energy source: development and challenges. *Procedia Engineering*, *56*(39), 39–53. https://doi.org/10.1016/j.proeng.2013.03.087.

[42] Khan, M.M.; Khan, R.U.; Khan, F.Z.; Athar, M. (2013). Impacts of biodiesel on the environment. *International Journal of Environmental Engineering and Management*, *4*(4), 345–350.

[43] Shevade, V. S.; Loboda, T. V. (2019). Oil palm plantations in Peninsular Malaysia: Determinants and constraints on expansion. *PloS One*, *14*(2), 1–22. https://doi.org/10.1371/journal.pone.0210628.

[44] Comte, I.; Colin, F.; Whalen, J.K.; Grünberger, O.; Caliman, J.P. (2012). Agricultural Practices in Oil Palm Plantations and Their Impact on Hydrological Changes, Nutrient Fluxes and Water Quality in Indonesia: A Review. *Advances in Agronomy*, *116*, 71–124. https://doi.org/10.1016/B978-0-12-394277-7.00003-8.