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# Feasibility of Hydroprocessed Esters and Fatty Acids (HEFA) for Use as Automotive Fuels in the ASEAN Economic Blocs

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**ABSTRACT** – *Renewable diesel has been used as a substitute for diesel to resolve the depletion of crude oil. A data-driven modeling approach is conducted to study the production of potential and profitable Hydroprocessed Esters and Fatty Acids (HEFA) for diesel engine usage in ASEAN, ASEAN Plus Three (ASEAN+3), and ASEAN Plus Six (ASEAN+6) economic blocs. This study covers a total of 13 countries which comprises seven selected member states in ASEAN, three additional East Asian states in ASEAN+3, and another three extra Asia-Pacific countries in ASEAN+6. The profitable HEFA production at crude oil price = RM236/bbl is investigated under 3 different subsidy scenarios, namely no subsidy, partial subsidy (government subsidy), and full subsidy (government subsidy + market opportunity). The economic feasibility of HEFA in each country is classified into three main limiting factors which are the crude oil price, feedstock quantity, and Herfindahl-Hirschman Index in this model. In the no subsidy scenario, our model shows that the profitable HEFA production of ASEAN member states is uniformly limited by the crude oil price with only Myanmar being limited by feedstock quantity. Our model also shows that even though the neighboring Asia-Pacific countries are factored in, there will not be an increase in the profitable HEFA production at crude oil price = RM236/bbl under any subsidy scenarios. This study provides insights for governments to generate automotive policy about the cooperation of ASEAN member states with other countries through the ASEAN+3 and ASEAN+6 regarding renewable clean diesel energy.*

**KEYWORDS:** Hydroprocessed Esters and Fatty Acids (HEFA), sustainability, ASEAN, bio-fuels subsidy, diesel engines



## 1. INTRODUCTION

As the global oil demand has been increasing over years, from 86.4 million barrels per day in 2010 to 96.5 million barrels per day in 2021 (Sönnichsen, 2021), such over-exploitation of the non-renewable crude oil reserve has become a major global problem to be resolved. This increase in crude oil demand is exacerbated in Asia due to the region being among the fastest-growing economic blocs (Ng et al., 2017). As such, there is a twin issue of environmental and oil depletion concerns for all economic sectors, including the automotive sector. Therefore, the replacement of diesel with the upcoming alternative fuel such as Hydroprocessed Esters and Fatty Acid (HEFA) will be a potential solution to support the green energy agenda in the Asia region. Many studies have been carried out to investigate the feasibility of HEFA in the automotive industry. This would include the process simulation and techno-economic analysis of HEFA production conducted by (Wang, 2019) to show the potential HEFA production with five different biofuel feedstocks under a range of minimum fuel selling prices of RM3.7688/L to RM11.3488/L in one of the Asian countries, namely Taiwan. A study that investigated the practical use of HEFA in compression ignition engines is also conducted by (Sonthalia & Kumar, 2019), showing the combustion performance and emission behavior of HEFA to be comparable to that of fossil diesel. Recently, De Souza et al. (2020) utilized the Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to research seven oleaginous biofuel feedstocks to determine the most productive, sustainable, and competitive feedstock in southeast Brazil for HEFA production. Despite the numerous studies regarding HEFA production, there has been an absence of research on the viability of HEFA production for the automotive industry in Asia under the current market scenario.

Hence, a data-driven modeling methodology is employed to evaluate the feasibility of profitable HEFA production under three subsidy scenarios for various Asia economic blocs, namely ASEAN, ASEAN+3, and ASEAN+6. Therefore, this study projects the potential reduction of fossil fuel reliability that could be achieved by regional cooperation of ASEAN with East Asia and Asia-Pacific countries.

## 2. METHODOLOGY

In this paper, a data-driven model was used to analyze the production of Hydroprocessed Esters and Fatty Acids (HEFA) under various economic scenarios for the ASEAN economic blocs. This model is modified from the previous biodiesel model by Chong et al. (2021), with the addition of HEFA fuel for the automotive sector. The model data were primarily sourced from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), the United States Department of Agriculture (USDA), and UNdata.

A total of 16 oil-based feedstocks are incorporated in this model which are castor oil seed, coconut, cottonseed, kapok fruit, groundnut, linseed, maize, oil palm fruit, olives, palm kernel, rapeseed, safflower seed, sesame seed, soybeans, sunflower, and rice paddy. Three processing costs set in this model are RM1.3192/L, −RM0.7606/L, −RM2.0085/L which correspond to scenarios under no subsidy, partial subsidy, and full subsidy respectively. A crude oil price of RM236/bbl is used in this model to maintain market recency.

This model has taken into consideration of seven member states in ASEAN, three extra East Asian states in ASEAN+3, and additional three Asia-Pacific countries in ASEAN+6 due to existing second-generation biofuels feedstock plantations in each of these countries. The processing costs used in this model are modeled after that of the US government incentives and market opportunity (Renewable Identification Numbers – RINs). A feedstock threshold of 10 tons of exported lipid per day is also set to ensure large-scale HEFA production.

### 2.1 Potential HEFA Production Volume

For potential and profitable HEFA production, our model takes into consideration the exported feedstock quantity of each country. Domestic sales of feedstocks and its products are assumed to be just sufficient in securing food supply in each country, therefore unable to be converted for HEFA production. Only feedstocks with export quantities larger than the feedstock threshold are utilized for HEFA production to ensure a minimum production scale. Four recurring factors, feedstock type, country, processing cost, and crude oil price are assigned the subscripts (a, b, c, and d) respectively.

The potential HEFA production volume, $HEFAP\_P_{ab}$, is the undeveloped HEFA production potential without accounting for profitability for each country. It relies heavily on the usable lipid quantity, $ULQ\_P_{ab}$, which represents the and total lipid quantity in exported feedstock that exceeds the feedstock threshold for each country.

$$HEFAP\_P_{ab}=\frac{ULQ\_P_{ab}\times HY}{BD} \tag{1}$$

where the yield of HEFA from lipid product is denoted as $HY$, while $BD$ is the biodiesel density. Biodiesel density is used for unit conversion of HEFA produced from kilogram into litre.

### 2.2 Upper Boundary Export Value

The upper boundary export value, $UBEV\_PrP_{abcd}$, is the highest cost per kilogram of lipid for HEFA production to be profitable. It is highly dependent on market's jet fuel price and the processing cost of HEFA production route in order to be sensitive in reflecting market's condition.

$$UBEV\_PrP_{abcd} = \left[\left(\frac{JFP_d}{JD}\right) - \left(\frac{PC_c}{BD}\right)\right] \times HY \quad (2)$$

where $JFP_d$ represents the jet fuel price per unit volume, while $PC_c$ denotes the total processing cost of HEFA production without accounting for feedstock cost. A simple linear relation analysis is done between jet fuel price and crude oil price for a 20-year range price, and it is a better indicator than diesel price due to the role of HEFA as alternative jet fuel in ASTM7566. The analysis generally shows linear correlation, allowing the conversion of crude oil price of RM236/bbl into jet fuel price of RM287/bbl. Jet fuel density, $JD$ and biodiesel density, $BD$ are used for unit conversion from volume into kilogram. The HEFA production yield is represented by $HY$, which covers the overall conversion rate from feedstock lipid to the final HEFA product.

### 2.3 Profitable Potential HEFA Production Volume

The profitable potential HEFA production volume, $HEFAP\_PrP_{abcd}$, is the maximum potential HEFA production of a country with the minimum financial criteria of breaking even, as shown below:

$$HEFAP\_PrP_{abcd} = \begin{cases} HEFAP\_P_{ab} & , UBEV\_PrP_{abcd} > LEV\_PrP_{ab} \\ 0 & , UBEV\_PrP_{abcd} \leq LEV\_PrP_{ab} \end{cases} \quad (3)$$

where $LEV\_PrP_{ab}$ is the lipid export price for each country, which takes feedstock export price multiplied by feedstock lipid content. Profitable HEFA, $HEFAP\_PrP_{abcd}$, is taken as a subset of potential HEFA production, $HEFAP\_P_{ab}$, which profitable are assumed as HEFA selling price being lower than jet fuel market price.

## 3. RESULTS AND DISCUSSION

### 3.1 Potential HEFA Production

The additional production of HEFA is estimated by assuming all exported feedstock for each country can be converted into HEFA. It shows the potential of a country to help determine whether is it worth developing their technology in renewable diesel sector.

Figure 1 shows the potential HEFA that can be produced by each country without the constraint imposed by the economic scenarios. The production of related countries is summed and is classified into ASEAN, ASEAN+3, and ASEAN+6. As shown in Figure 1, ASEAN member states could contribute to the majority of the potential HEFA production with Indonesia and Malaysia as the largest contribution countries for 35% and 60% of the HEFA productions, respectively. By considering the regions, South-East Asian countries represented by ASEAN have the largest potential for HEFA production due to their large production of palm oil and coconut, where Indonesia and Malaysia are the current largest exporter of palm oil in the world.

For ASEAN+3, China takes the lead for potential HEFA production among the additional three East Asia states followed by Japan and Republic of Korea. In ASEAN+6, India stands out being the third largest potential HEFA production country after Indonesia and Malaysia. This is based on the large export volume of soybean and castor beans in China and India, respectively. In the potential scenario, Myanmar and New Zealand will be the only two countries without any potential HEFA production capacity. This is because of their limited oil-based feedstock export quantities causing them to not meet the minimum requirement for large-scale productions.

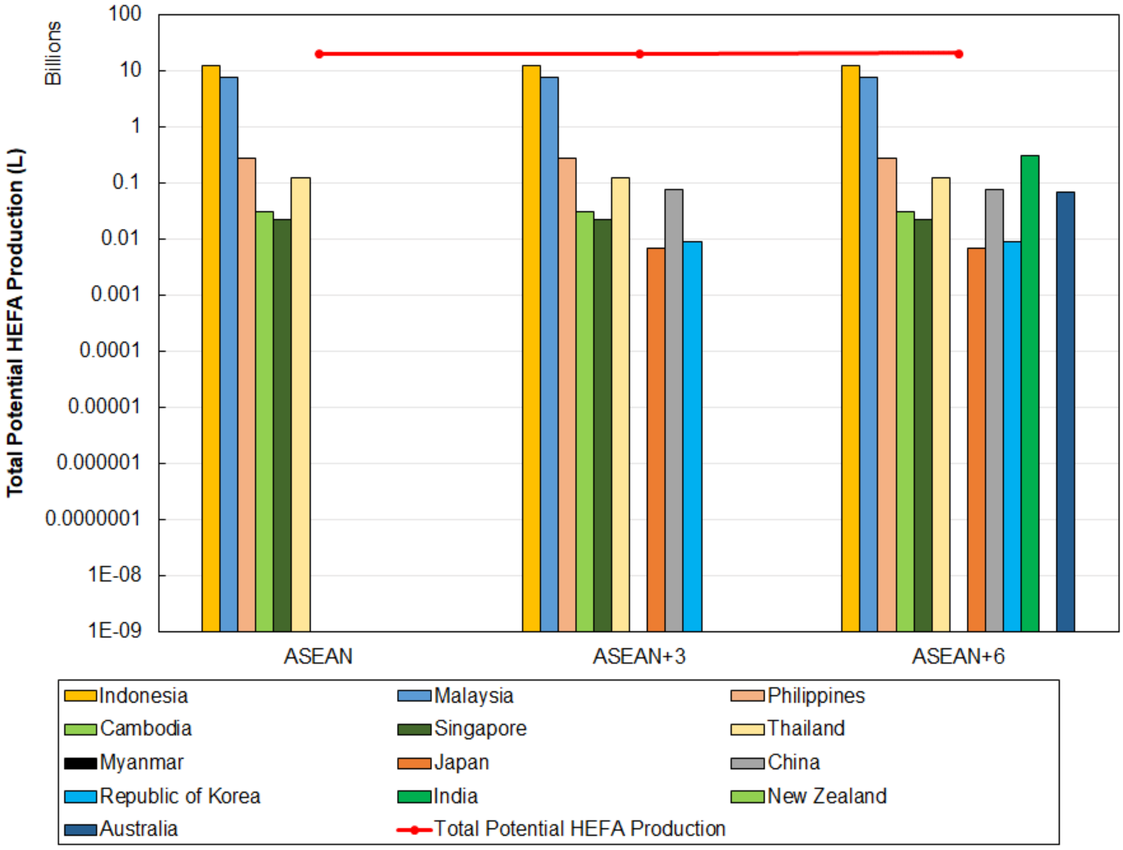


**FIGURE 1**: Potential HEFA production for each country in the ASEAN, ASEAN+3, and ASEAN+6 economic blocs

### 3.2 Profitable HEFA Production and Blending Ratio

The economic feasibility of HEFA production heavily relies on the independent variables of crude oil price and subsidies provided to producers. Figure 2 shows the total profitable HEFA production in each country under three different subsidy scenarios and their corresponding blending ratios. As the profitable HEFA will be a valuable quantity to enter the real market, the correlation between produced profitable HEFA and diesel consumption is represented by the blending ratio, providing an indication of the energy security in each country.

In the full subsidy scenario, there are two countries with the ability to produce profitable HEFA, namely the Philippines and Cambodia. They could reach blending ratios of 0.14% and 1.84% respectively. The Cambodian Working Group for Analysis of Energy Saving Potential in East Asia, under the Economic Research Institute for ASEAN and East Asia (ERIA), has proposed a target of 10% of road transport diesel in Cambodia will be replaced by domestic biodiesel production by year 2030 (Asian Development Bank, 2015). Our study suggests that policies for renewable energy should be developed by the Cambodian government to also include HEFA as a potential road transport fuel for diesel engines to meet the target.

Under the no subsidy scenario, all countries investigated have produced zero liters of profitable HEFA. This means that without any subsidy, none of the investigated country had the ability to produce HEFA economically under current market conditions. Even Malaysia and Indonesia would not have profitable HEFA production as the high export value of palm oil makes it far more profitable than converting feedstock into HEFA for market consumption for both countries.

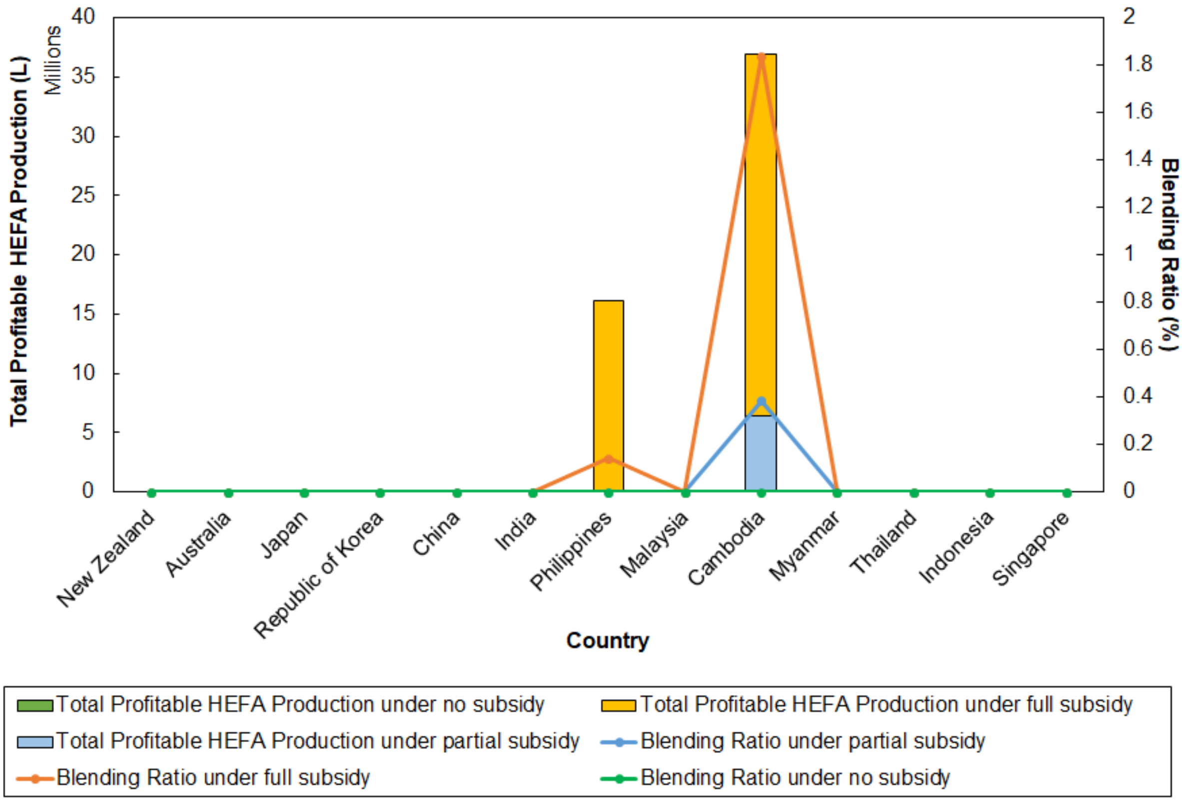


**FIGURE 2**: The current and potential energy mixes of the EU across different enlargement phases

It is forecasted that the combination of the demand and supply dynamics of crude oil will initiate a supercycle, which eventually leads to a crude oil price of US$ 190/bbl (equivalent to RM785/bbl now) in the year 2025 (Malek et al., 2020). Under this scenario, the profitable HEFA production in Japan and China could have a breakthrough from zero liters to 1.97 million liters and 14.4 million liters, respectively, albeit with government subsidies. Therefore, our study suggests that the cooperation of ASEAN and the three additional East Asia countries in ASEAN+3 will be beneficial for the automotive sector with respect to its use of renewable energy.

### 3.3 Limiting Factor of Profitable HEFA Production

In this model, three limiting factors that will prevent profitable HEFA production in each country are evaluated, namely crude oil price, feedstock quantity, and Herfindahl-Hirschman Index. Crude oil price shows the profitable aspect of the HEFA market, feedstock quantity expresses the constraint of exported feedstock amount for HEFA production, while Herfindahl-Hirschman Index represents the energy diversity of each country after accounting for profitable HEFA produced.

Figure 3 shows the limiting factor for profitable HEFA production in ASEAN, ASEAN+3, and ASEAN+6 under no subsidy scenario. In the no subsidy scenario, majority of countries are limited by crude oil price while only Myanmar and New Zealand are constrained by feedstock quantity. Our model has assumed that profitable production is a subset of potential production, therefore oil-based feedstock scarcities in Myanmar and New Zealand have led to their prioritization of these feedstocks on domestic usage instead of treating them as export commodities. None of the countries should be concerned by their energy diversity as the use of HEFA for their automotive sector will improve diversity, considering their energy mix is heavily reliant on fossil diesel.

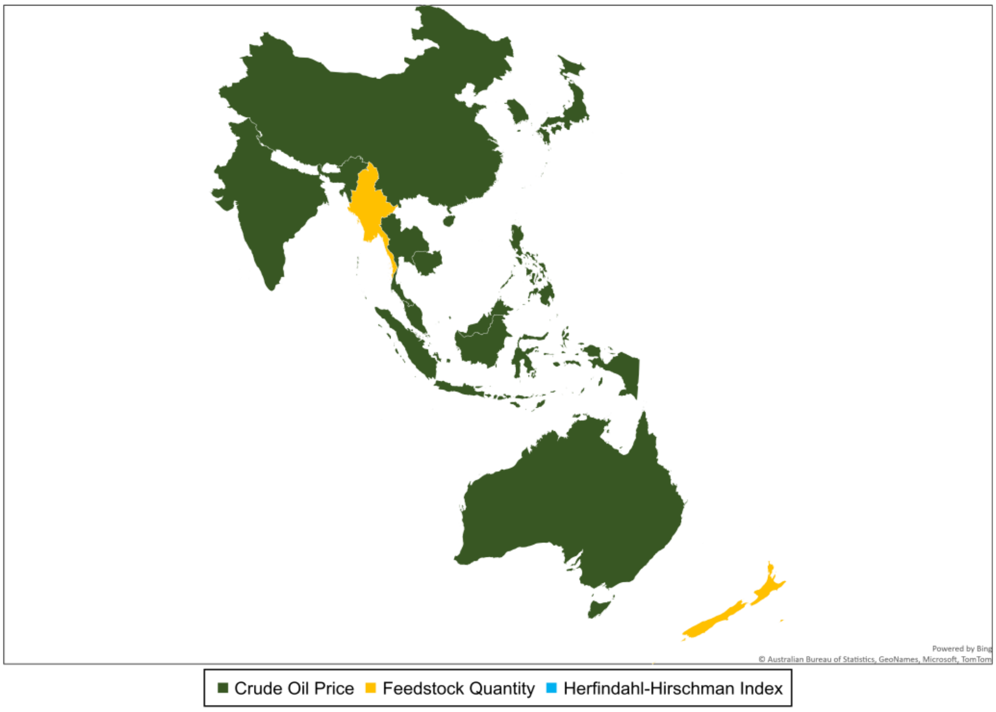


**FIGURE 3**: Limiting factor for profitable HEFA production under no subsidy scenario in ASEAN, ASEAN+3, and ASEAN+6

## 4. CONCLUSION

In this study, a data-driven model is established to evaluate the feasibility of HEFA production as a replacement for diesel fuel for the automotive industry under current market conditions in ASEAN, ASEAN+3, and ASEAN+6. The model determines the relationship between HEFA production and independent economic factors, such as crude oil price and subsidy, to display the profitable HEFA production of ASEAN economic blocs. The result shows that countries with the highest potential HEFA production in ASEAN member states are Malaysia and Indonesia, which accounted for 35% and 60% of HEFA production in ASEAN economic blocs. At a HEFA processing cost of RM1.3192/L, none of the investigated economic blocs would have the ability to produce profitable HEFA without any subsidy. For profitable HEFA production, Myanmar and New Zealand are being limited by the low availability of feedstock quantity, while the rest of the countries investigated are restricted by the low market price of crude oil under the no subsidy scenario. This indicates that countries with large oil-based feedstock export quantities will have a high potential for HEFA production, but their profitability is restricted when the export value is high.

In short, our model shows that the cooperation of ASEAN with East Asia and Asia-Pacific countries into ASEAN+3 and ASEAN+6, respectively, has minimal impact on the feasibility of profitable HEFA production for the automotive industry without government support. It is recommended that a minimum of RM2.00/L subsidy needs to be provided through a more supportive ASEAN renewable energy policy to trigger the profitable HEFA production in the region. This study could serve as a guideline for governments to develop HEFA as alternative diesel fuel for the automotive industry.

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