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Effects of European Union Enlargement on the Viability of Hydroprocessed Esters and Fatty Acids Production Usage in Diesel Engines

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ABSTRACT – *The utilization of crude oil-derived diesel fuel has undeniably contributed to the adverse environmental effects in the European Union (EU). To align with the European Council's mandate to increase the shares of renewable energy consumed, it is important to facilitate the implementation of renewable diesel fuel in the EU automotive sector. Using an Energy-Water-Food (EWF) nexus approach, a data-driven model was established to investigate the sustainability of Hydroprocessed Esters and Fatty Acids (HEFA), which has dual usage as diesel engine fuel and sustainable aviation fuel (SAF). In this model, a total of three EU enlargement phases and Brexit (namely, EU-12, EU-28, EU-27, and one projected enlargement), were considered. The analysis was conducted on 43 selected European countries, including six Eurasian states. The scenario combinations cover three different subsidy schemes at the same crude oil price of €100/bbl. When a full subsidy scheme is applied, the Czech Republic, Germany, Hungary, Ireland, Turkey, and Ukraine can have profitable HEFA production. However, only Czech Republic has the potential to produce HEFA profitably under the partially subsidized condition if all the exported palm oils are retained in the country. Most of the European countries have their sustainable HEFA production limited by crude oil price and feedstock quantity, attributed to the high processing cost and tight feedstock supplies. The future biofuel and waste energy shares of the enlarged EU (EU-43) are shown to be the worst, followed by EU-12, EU-28, and EU-27 (after Brexit). Despite the low contributions of HEFA as a diesel engine fuel to meet the EU renewable energy regulations, however, it will be prudent to include HEFA as part of the mid-term energy solution mix.*

KEYWORDS: Hydroprocessed Esters and Fatty Acids (HEFA), diesel engine, European Union (EU), energy mix, limiting factors

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1. INTRODUCTION

The low amount of oil reserves has caused the EU-27 to have a very high oil import dependency of 96.77% (Eurostat, 2021). Within the context of the automotive sector, a rise in the crude oil price will increase the demand for alternative fuel as a replacement for diesel fuel. Due to the high volatility of oil prices, the present heavy reliance of 47.7% (Eurostat, 2021) on petroleum products for the automotive sector will be unsustainable financially and environmentally in the long run. One possible solution is the extraction of lipid contents from oil crops to produce sustainable diesel fuel. Hydrotreated vegetable oil (HVO), more commonly referred to as Hydroprocessed Esters and Fatty Acids (HEFA) is an option. It is a mature and commercially available lipid-conversion technology primarily used to produce drop-in jet fuel, but with the potential to be used for diesel engines within the automotive sector.

Puricelli et al. (2021) stated that the growth of transport biofuels consumption occurred in 2017-2018 can be attributed to the European biofuel legislation push, at which 62.3% of biofuels consumed were biodiesel, followed by 17.5% of bioethanol and 16.6% of green diesel or hydrotreated vegetable oil

(HVO). According to Zeman et al. (2019), the BS EN 15940 standard applies to HEFA fuel for use in diesel engines. Despite the increasing number of research studies conducted in recent years, there is still a lack of studies regarding the relationship of the EU's enlargement with its HEFA production for road transport purposes.

In this study, a data model was established to investigate the sustainability of HEFA production for past and projected EU enlargement agenda, in a bid to offer a different insight for the EU's decision-makers.

2. METHODOLOGY

The low amount of oil reserves has caused the EU-27 to have a very high oil import dependency of 96.77% (Eurostat, 2021). Within the context of the automotive sector, a rise in the crude oil price will increase the demand for alternative fuel as a replacement for diesel fuel. Due to the high volatility of oil prices, the present heavy reliance of 47.7% (Eurostat, 2021) on petroleum products for the automotive sector will be unsustainable financially and environmentally in the long run. One possible solution is the extraction of lipid contents from oil crops to produce sustainable diesel fuel. Hydrotreated vegetable oil (HVO), more commonly referred to as Hydroprocessed Esters and Fatty Acids (HEFA) is an option. It is a mature and commercially available lipid-conversion technology primarily used to produce drop-in jet fuel, but with the potential to be used for diesel engines within the automotive sector.

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In this study, a data model was established to investigate the sustainability of HEFA production for past and projected EU enlargement agenda, in a bid to offer a different insight for the EU’s decision-makers.

TABLE 1: Lists of European countries according to each EU enlargement agenda

Phases (Year)	Countries
EU-12 (1993)	Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, United Kingdom
EU-28 (2013)	**EU-12 +** Austria, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Finland, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia, Sweden
EU-27 (2020)	**EU-28 –** United Kingdom (Brexit)
EU-43 (Future)	**EU-27 +** Albania, Andorra*, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Georgia, Iceland*, Kazakhstan, Kosovo*, Liechtenstein*, Moldova, Monaco*, Montenegro*, North Macedonia, Norway, Russian Federation, San Marino*, Serbia, Switzerland, Turkey, Ukraine, United Kingdom, Vatican City*

** Excluded from the model.*

A currency rate of 0.753 is used to convert from United States Dollar to Euro. The HEFA's market price was modeled as €100/bbl, which is the highest nominal crude oil price between July 2001 and July 2021. Three different subsidy schemes (none, partial and full) were factored into the HEFA's processing cost, based on the government incentives and market trading programs. Four subscripts (a, b, c, and d) were assigned to each recurring factor, specifically the type of feedstock, country, processing cost, and crude oil price, respectively.

2.1 Usable Lipid Quantity

The minimum feedstock quantity required was set at 10 tonnes per day. Under the potential scenario, the usable lipid quantity (ULQ_{ab}), which is the amount of lipid that can be extracted for HEFA production, are related to the feedstocks' exported quantities (EQ_{ab}) and provided that EQ_{ab} exceeded the threshold value.

$$ULQ_{ab} = \begin{cases} EQ_{ab} \times OC_a & , EQ_{ab} > 3650 \text{ tonnes} \\ 0 & , EQ_{ab} \leq 3650 \text{ tonnes} \end{cases} \tag{1}$$

where OC_a is the oil content of the corresponding 16 feedstocks, in wt%.

2.2 Lipid Export Value

The lipid export value per unit mass (LEV_{ab}) can also be determined from the unfiltered lipid quantity, as follows:

$$LEV_{ab} = \frac{EV_{ab}}{EQ_{ab} \times OC_a} \tag{2}$$

where EV_{ab} is the export value of the exported feedstocks.

2.3 Upper Boundary Export Value

The upper boundary export value per unit mass ($UBEV_{abcd}$) represents the highest possible cost acceptable by the market to produce HEFA to replace the existing diesel in the market. It is dependent on the crude oil price per unit volume (COP_d) and processing costs per unit volume (PC_c), which can be €0.3154/L, −€0.1818/L and −€0.4802/L under zero, partial and full subsidy scenarios respectively. $UBEV_{abcd}$ is represented by:

$$UBEV_{abcd} = \left(\frac{COP_d}{DD} - \frac{PC_c}{BD} \right) \times HY \tag{3}$$

where DD is the diesel density, BD is the biodiesel density and HY is the HEFA yield.

2.4 HEFA Production Volume

To ensure the profitability of HEFA production, the current LEV_{ab} of the feedstocks must be lower than $UBEV_{abcd}$. The HEFA production volume ($HEFAP_{abcd}$) can be calculated accordingly, as shown in equation (4).

$$HEFAP_{abcd} = \begin{cases} \dfrac{ULQ_{ab} \times HY}{BD} & , LEV_{ab} < UBEV_{abcd} \\ 0 & , LEV_{ab} \geq UBEV_{abcd} \end{cases} \tag{4}$$

The limiting factor for each country can then be decided from a pool of four: crude oil price, feedstock quantity, Herfindahl-Hirschman Index (HHI) and water stress, using the calculated $HEFAP_{abcd}$ value. It should be noted that HHI was used to compute the energy diversity for each European sovereign state.

3. RESULTS AND DISCUSSION

3.1 Profitable Potential HEFA Production

Tables 2 and 3 tabulate the ratio of HEFA production volumes to their corresponding diesel consumption volumes for selected countries and the EU's enlargement phases, respectively. All European countries will have their blending ratios lower than 1% regardless of the formation of larger entities. As shown in Table 2, it is obvious that the HEFA production must rely on some degree of subsidies. A total of six

European countries can produce HEFA profitably under fully subsidised conditions. If the process is being funded by the government only, the Czech Republic can continue its HEFA production to obtain a profit. This will be possible if all the exported palm oils are retained in the country for HEFA production only.

TABLE 2: Volume of diesel consumed and HEFA produced in the European countries

Countries	Diesel Consumption (L)	HEFA Production, *HEFAP*$_{abcd}$ (L)		
		Full Subsidy	Partial Subsidy	Zero Subsidy
Czech Republic	5,733,906,605	2,756,930	2,756,930	0
Germany	2,173,653,410	5,254,422	0	0
Hungary	99,585,152,932	15,383,586	0	0
Ireland	3,106,413,472	5,464,594	0	0
Turkey	27,322,345,635	41,122,959	0	0
Ukraine	6,586,647,558	15,880,895	0	0

TABLE 3: Volume of diesel consumed and HEFA produced in four EU's enlargement agenda

Enlargement Phases	Diesel Consumption (L)	HEFA Production, *HEFAP*$_{abcd}$ (L)		
		Full Subsidy	Partial Subsidy	Zero Subsidy
EU-12	69,007,043,897	10,719,017	0	0
EU-28	282,045,058,581	18,140,515	2,756,930	0
EU-27	250,325,244,894	18,140,515	2,756,930	0
EU-43	461,166,135,680	85,863,386	2,756,930	0

It is also promising that the addition of Turkey (European Commission, 2021) and Ukraine (Eastern Partnership, 2021), which are the candidate and an Eastern partner, respectively, will be beneficial to the EU from a renewable perspective, considering they are the top two countries with the highest potential to produce HEFA profitably with full subsidy. Although Turkey and Ukraine can potentially contribute to half of the projected EU-43's HEFA supply, this will only be sufficient to increase the blending ratio of the current EU-27 from 0.007% to 0.01%. At this stage, any form of EU can't produce B20 biodiesel, which is well-balanced in terms of cost, emission, cold-weather performance, materials compatibility, and solvation (Alleman et al., 2016).

Regardless, the technology readiness level of 9 for HEFA production makes it a mature process (Chong & Ng., 2021), which merits the consideration of the European Commission to contemplate increasing and diversifying their current subsidy schemes and legislations, such as the Energy Policy Act, to encourage the use of HEFA in the transport sector.

3.2 Energy Mix

As portrayed by Figure 1, the primary energy balances' data is obtained for the years 2018 and 2019. The only difference between the current and potential energy mix is the latter factored in the amount of energy contained in the HEFA produced under the potential scenario. It is observed that the UK's decision to quit the EU in 2020 has minimal effect on the renewable energy shares presently (16%, same for both), but EU-27 can have a 1% higher renewable energy mix after Brexit under the potential scenario.

The current and potential renewable energy shares are increasing in the order of EU-43, EU-12, EU-28, and EU-27 (after Brexit). This is due to most of the non-EU states having crude oil and natural gas as their main energy sources, while the current member states have made headways into increasing the proportion of renewable energy in the energy mix. Overall, the renewable energy shares of the EU, regardless of each accession stage, can be increased by diverting lipids of would-be exported products only.

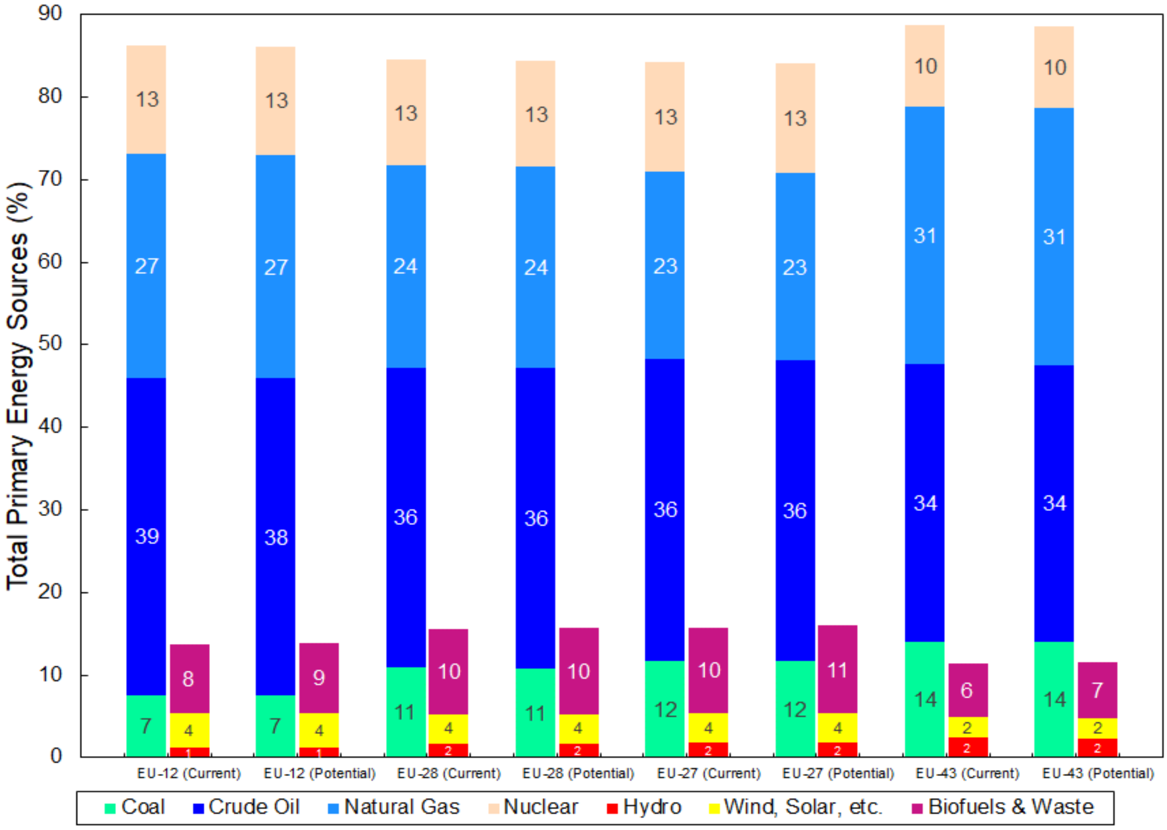

FIGURE 1: The current and potential energy mixes of the EU across different enlargement phases

Despite the exclusion of other energy balances such as electricity, heat, and oil products from this model, 16% is still considered an underestimation of the current renewable energy shares of the EU-27. According to the more-inclusive Eurostat database (2020), the EU has reportedly consumed 19.73% renewable energy, which is only 0.27% shy of the 20% target, while producing HEFA will certainly help the EU to reach the target.

3.3 Limiting Factors

As elucidated in Figure 2, most of the European countries have their sustainable HEFA production limited by crude oil price and feedstock quantity. This can be attributed to the high processing cost of HEFA and tight crop oil feedstock supplies in the region. When the subsidy decreases, the limiting factors of the Czech Republic, Germany and Hungary will change from energy diversity to crude oil price. Finland is the only exception here as it will face water stress if it produces HEFA from exported products, regardless of the subsidy schemes applied. This is because of the existing facility in the country that has drawn water sources for HEFA production (European Alternative Fuels Observatory, 2020).

A higher crude oil price can make HEFA production more profitable. This is achievable if the EU considers limiting the import of natural gas and coals from other continents, especially Asia. It is also possible if the shortages of non-renewable energy sources occur, the HEFA production will serve as a valuable backup plan for the EU's automotive industry.

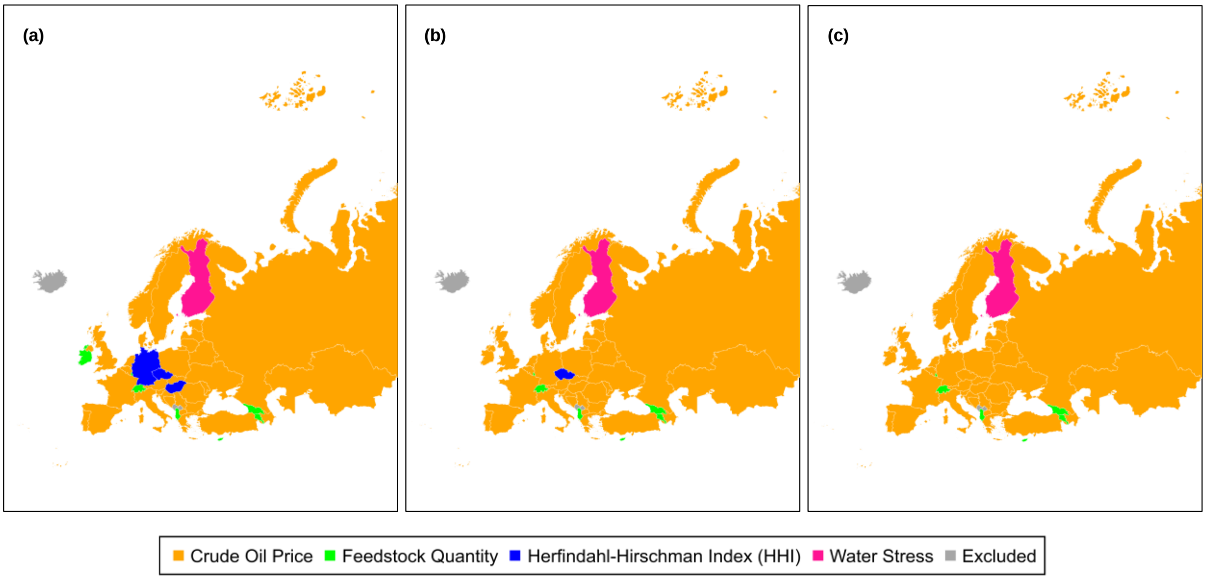

FIGURE 2: The limiting factors of each European country under (a) fully, (b) partially, and (c) without subsidized conditions

4. CONCLUSION

The model in this study analyzed the relevant datasets to evaluate the sustainability of HEFA production in each European country and selected the EU's enlargement phases. Hypothetical scenarios were projected where lipid products were used for domestic HEFA production instead of exports under different economic climates. By swapping the lipid feedstocks export for HEFA production in the year 2019, the EU-27's renewable energy shares' target of 20% in the year 2020 could be achieved. The high potential HEFA production volumes of Turkey and Ukraine will provide additional merits from the energy and environmental sustainability perspectives for their inclusion in the next EU's enlargement agenda. However, this will only be possible under high subsidies and high crude oil prices, at which the latter is very crucial as it determines the profitability of HEFA production in most of the European states. In conclusion, the model shows that HEFA could feature as part of the energy mix for a sustainable road transport sector in the EU. It should be noted that the potential of HEFA could be greater if the model included feedstocks such as used cooking oil (UCO) and animal fats. Thus, the establishment of a standardized and coercive EU's international fuel trading policy that streamlines the HEFA imports and exports in the region should justify considerations in any future EU's enlargement phases.

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