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Impacts of International Commodity Trade on Conventional Biofuels Production

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Abstract: The study gives an overview of raw materials and biofuel generation, markets, production, and regulation. The major aim of this study was to reveal the impacts of biofuel production on international commodity trade. According to the results of the country-level regressions, the export of corn and sugar cane have generally negatively impacted ethanol production. This effect was positive at the global level which indicates that some of the imported raw materials are used for ethanol production. Although the explanatory power of the models was relatively high (from 0.35 (EU) to 0.94 (USA)), none of models proved to be significant, even at the 10% level. These values were higher for the biodiesel models (from 0.53 (USA) to 0.97 (Brazil)) and the EU model results were significant at the 5% level. The export of raw materials had a positive impact on biodiesel production. This implies that some part of the biodiesel was produced from the imported raw materials. The export of processed products (different oils) had a negative impact on biodiesel production, as they are normally used for other purposes.

Keywords: biofuels market; blending rates; GHG emission savings; international trade

1. Introduction

The fossil energy resources of the Earth are finite, and their continued use causes ever-lasting damage to the environment through global warming and pollution [1]. Within a very short period of time, humanity must switch to the use of renewable energy sources with as little further waste and degradation to soil, water, and air as possible [2]. Renewable energies may provide a long-term solution to our energy needs and, to mitigate climate change in the short-term, several technical issues remain to be overcome. The most notable ones are unbalanced production (e.g., between photovoltaic and wind energy) and efficient energy storage systems that help to adjust production to consumption (e.g., energy need in windless periods or in the dark). Carbon dioxide emissions remain a relevant concern as a major greenhouse gas (henceforth referred to as GHG) which significantly contribute to global warming. Biofuels could minimize this issue, as only previously absorbed carbon dioxide is released through burning, such that in this regard they can be produced in a sustainable way.

First generation biofuels are mainly ethanol and biodiesel, and other types of biofuels (e.g., biobutanol, biogas) as well as next generations will not be analyzed in this study. Ethanol is basically produced from plants with high sugar (sucrose) or starch contents, while for biodiesel production, mainly vegetable oils are used. The latter is more important in Europe, as the share of diesel cars is much higher than in the United States [3].

Although the use of biofuels is GHG neutral, during its production process (cultivation, seed production, use of fertilizers and herbicides, harvest, and processing), the emission level of GHGs can be significant. However, even this emission is far lower than the amount released from burning fossil resources. This article is restricted to biofuels, other renewable energies may have even lower emissions.

At this moment, commonly used raw materials (i.e., corn or sugarcane for ethanol, rapeseed or soybean for biodiesel) can directly be used for food production or feeding. Therefore, it is worth exploring the potential impacts of biofuel production on the commodity markets, especially on international trade. This paper's major research aim was to study the connection between the continuously growing biofuel production and the export of the major raw materials and processed products different from biofuels. It is a rarely researched topic because of its special characteristics. From an international trade point of view, biomass commodities, including biofuels, are heterogenous; therefore, trade drivers and barriers are different [4].

2. Materials and Methods

Biofuel markets can be described by production data, which is available at the Renewable Fuels Association (henceforth referred to as RFA) database [5] for ethanol and the joint database of the Organisation for Economic Co-operation and Development/Food and the Agriculture Organization of the United Nations [6] for biodiesel. Production cost data may vary from source to source, but this study used the latest available literature. Different yield data (maize, soybean, and rapeseed) can be downloaded from the database of the Food and Agriculture Organization of the United Nations [7]. Data on US maize use can be retrieved from the US Department of Energy, Alternative Fuels Data Center [8].

Unlike biofuel production data and ethanol trade data, international biodiesel trade data (3826—Biodiesel and mixtures thereof, not containing or containing less than 70 % by weight of petroleum oils or oils obtained from bituminous minerals) is available only from 2012, which is the greatest limitation of the study. The World Integrated Trade Solution (WITS) Harmonized System (HS) 2012 classification was used at a 6 digit level (chapter–heading–subheading) [9]. The analyzed countries are the top three biofuel producers: Brazil, the European Union (EU), and the US. The analysis contains corn (USA) and sugarcane (Brazil), the most important raw materials for ethanol production. Palm, soybean, and rapeseed are the major commodities used worldwide for biodiesel production [10]. Correlations were calculated and tested between the independent variables in Microsoft Excel, and in case of high correlation ($\rho > 0.7$), always the independent variable with lower export value was excluded from the regression model. For regression analyses, 3.21 version of "Past" software was used.

3. Major Characteristics of Biofuels

3.1. Raw Materials and Generations

Regarding first generation biofuels, having a high sugar or starch content is the most important factor for ethanol, while a high oil content is necessary for biodiesel fuel. Due to this, there is a conflict of interest with human nutritional needs, as mostly grains are used for production. What is essential is to determine the allocation of resources either for eating or travelling. Therefore, it is vital to find other raw materials for biofuel production in order to not jeopardize food security. The competition between biofuels and food security has been deeply analyzed by Koizumi [11,12]. One of his major findings was that even cellulosic-based biofuel production competes with food-related demand; therefore, this affects food security.

A common characteristic of the latest biofuel generations is that their raw materials can hardly be used for food industry purposes (e.g., straw, liquid manure or lignocellulose). However, this generates competition with other industries, e.g., cellulose is an important component for the textile and paper industries. The use of waste materials or by-products is an acceptable solution, because they provide an alternative method for biofuel production and help deal with waste management [13].

The fundamental problem with further biofuel generations is that they are immature and therefore more expensive than first generation production at this moment. This includes algae-based production which requires no land; therefore, it could be an ideal solution for biofuel production. Table 1 gives an overview of the biofuel generations; it includes possible feedstocks, conversion processes, and carbon balance.

Table 1. Biofuel generations.

Generations	Product	Feedstocks	Conversion Process	Carbon Balance
1st	Ethanol	Wheat, barley, corn, sugarcane	Fermentation	Positive
	Biodiesel	Rape, sunflower, palm, soybean, animal fat	Transesterification	Positive
2nd	Ethanol	Lignocellulosic materials	Fermentation	Positive
	Biodiesel	Jatropha and nonedible oils	Transesterification	Positive
3rd	Biodiesel	Algae and seaweeds	Algal synthesis	Negative *
4th	Ethanol	CO_2	Microbial synthesis	Negative

* It should be noted that the major element of the negative CO_2 balance is the replaced CO_2 in biodiesel production, which may not offset the total CO_2 emissions for all algae species and technologies [14]. Source: Author's composition based on Naik et al. [15].

For the first and the second generations, the conversion processes are fermentation for ethanol and transesterification for biodiesel, all with positive carbon balance outcomes. Beginning with the 3rd generation, synthesis is the main conversion process, and the carbon balance may become negative which means that these processes are at least CO_2 free.

3.2. Biofuel Markets

Although the production of biofuels is continuously growing, it should be noted that they compose only 2.3%–2.5% of the global oil use on average [16]. This percentage would be higher if only fuels are considered; however, this is limited by the blending rates. Seventy-one million hectares of land are allocated to biofuel production worldwide, where ethanol represents 62% of it while biodiesel raw materials account for 24% [17].

There was only one decrease in the production of ethanol during the analyzed period, from 2010 to 2012 due basically to the poor sugarcane harvest in Brazil as well as the high world sugar prices [18]. The Brazilian production started to recover only after 2012 (Figure 1). The major ethanol producer in the world is the USA, followed by Brazil, the EU, and China. All the other producers are represented by the rest of the world (RoW).

According to the RFA database, the share of the USA varied between 50% (2007) and 62% (2012), while it was between 84% (2013) and 89% (2008) when combined with Brazil. The EU had only a 5% share, while the Chinese production accounted for 3%. Based on the projections of the OECD and the FAO, the major producers will be the same and the following changes can be anticipated on the global ethanol market by 2027 [6]:

- The USA will remain the major producer; however, its market share will decrease to 46%;
- Brazil will not only keep its second position, but also strengthen it (25% market share);
- The EU's production will not remarkably change, resulting in a bit lower market share;
- China is going to increase its production and reach 8% market share by 2027;
- Otherwise, Thailand and India are going to increase their ethanol production and claim 2% global market share.

Compared to the ethanol market, the biodiesel market is smaller in terms of production and less concentrated (Figure 2). The EU is the leading producer with a continuously decreasing market share which went down from 56% to 34% during the analyzed period. The EU is followed by the USA with a market share of 19% in 2018. Brazil and Argentina were able to produce significantly more which resulted in higher market share (13% and 6%, respectively).

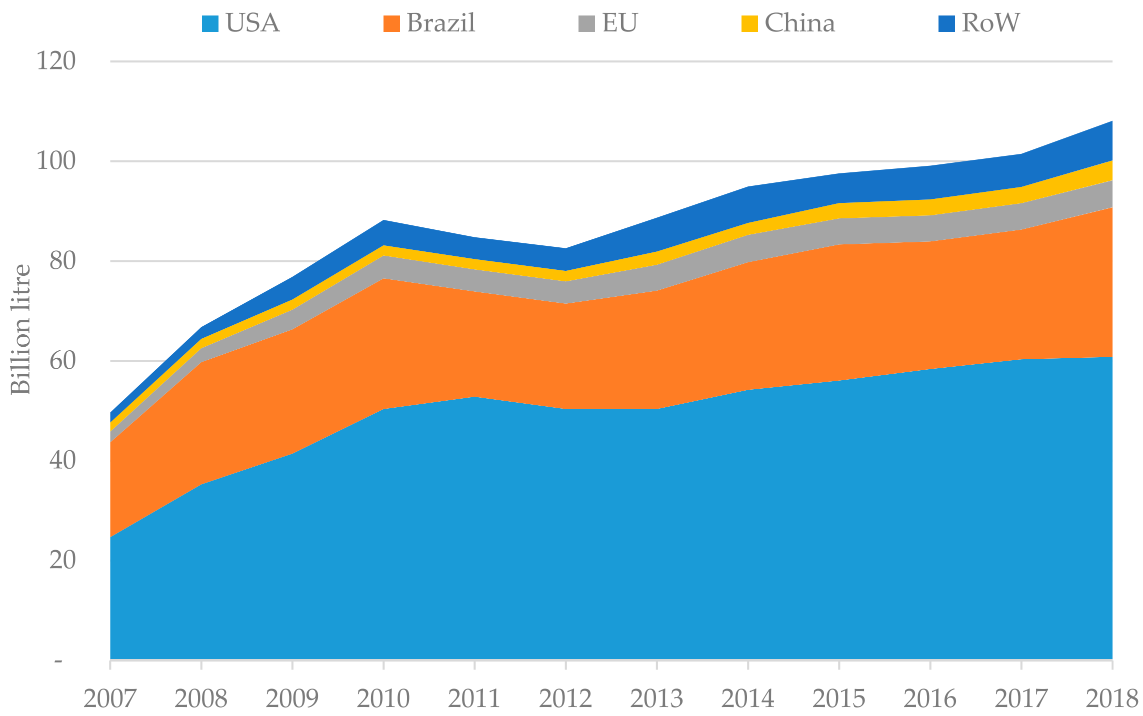

Figure 1. World ethanol production, 2008–2018. Source: Author's composition based on Renewable Fuels Association data [5].

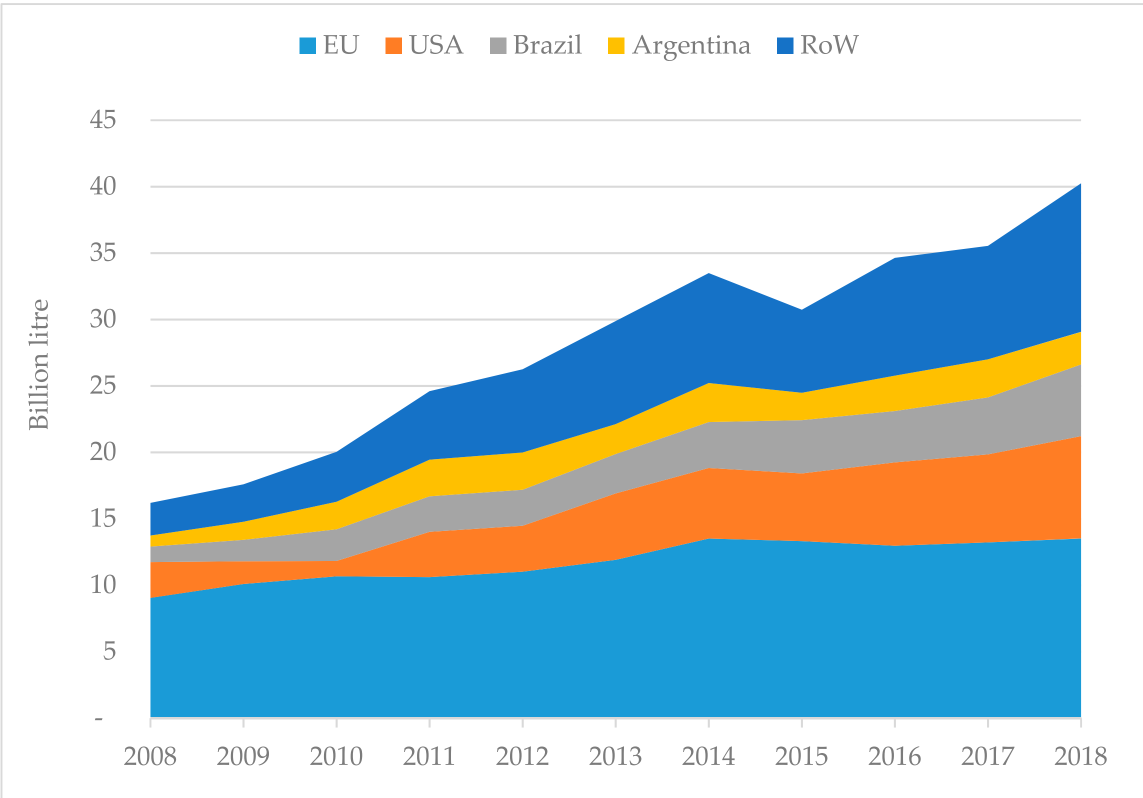

Figure 2. World biodiesel production, 2008–2018. Source: Author's composition based on OECD/FAO [6].

According to the OECD and the FAO, even the rank of major producers will change by 2027. The main elements of the anticipated transformation of the global biodiesel market are [6]:

1. The EU will keep its leading position but with a decreasing share (34% in 2027);
2. The EU will still be followed by the USA (17%) and Brazil (14%);
3. Indonesia is going to take 4th place with an 11% market share;
4. Argentina and Thailand will have a perceptible production difference from the rest of the world (8% and 5%, respectively).

3.3. Biofuel Production

3.3.1. Ethanol Production

As a matter of first-generation techniques, ethanol can be produced by dry- and wet-milling processes. Table 2 gives a comparison of them.

Table 2. Comparison of dry- and wet-milling process.

	Dry-Milling Process	Wet-Milling Process
Investment cost	Lower 51.8 million USD	Higher 79.3 million USD
Operating cost *	higher	lower
Technology	Milling, fermentation, distillation	Steeping, separation before fermentation
Ethanol yield (from 100 kg corn)	~34 kg	~29 kg
Co-products	~32 kg distiller's dried grains with solubles (90% dry content) and ~32 kg CO_2	~5 kg corn gluten meal, ~22 kg corn gluten feed, ~3 kg corn germ oil, fiber, feed steep water, and CO_2

* Operating cost decreases with the size of the biorefinery. As the major cost element is the raw material (see below); therefore, it is hard to compare them. Source: Author's composition based on Reference [19] (dry-milling cost), Reference [20] (wet-milling cost), and Reference [21].

As seen in the table above, dry-milling process results in a 10% higher ethanol yield, and the major co-product is DDGS (distiller's dried grains with solubles). This can be produced out of the highly perishable DGS (distiller's grains with solubles) by drying. However, drying DGS requires a huge amount of energy, but it extends its tenability; therefore, there is no need for it to be used strictly locally. DDGS is a popular feedstock in the USA, having a well-developed market. The DDGS price is closely correlated with the price of corn, fluctuating around 90% of the price of corn [22].

The wet-milling process results in lower ethanol yields, but co-products are more valuable. Corn gluten meal and corn gluten feed can be used for feeding. They have a 48%–60% and 18%–22% dry content, respectively. Corn germ oil is used by the food and cosmetics industry. But it should be noted that the continuous development of the processing techniques (optimized temperature, more efficient yeast, IT controlled processes) increases the ethanol yields at the expense of the co-products. Technically, this means smaller amounts of DDGS in the dry-milling process; however, its protein content becomes higher therefore becoming more valuable.

The major economic question of ethanol production (or biofuel production in general) is whether it is profitable to produce it or not. As it is the main substitute of normal gasoline, ethanol production prices should be compared to oil prices. Table 3 shows the production cost of ethanol in the major producer countries.

Based on production costs, Brazil can produce the cheapest ethanol. This is strengthened by the flexible production of the plants, as they can either produce ethanol or sugar, depending on which is more profitable. China and the USA use mostly corn, while in the European Union, other cereals (e.g., wheat) are also used. According to the latest oil prices (Brent oil is around 59 USD/barrel), ethanol production can be profitable under approximately 37 cents/liter production, giving around 37% more room for the Brazilian production. Under the current oil prices, the Chinese, US, and EU's production are not price competitive after the weighting.

Table 3. Production cost of the major ethanol producers (large plants).

Countries	USD/Liter	Weighted USD/Liter *
Brazil	0.18	0.27
USA	0.32	0.48
China	0.28–0.46	0.42–0.69
EU	0.45–0.79	0.68–1.19

* Weighting takes into account the lower energy content of ethanol which is about two-thirds of the oil [23]. Source: Author's composition based on References [24–26].

The majority of the cost for ethanol production comes from the price of raw materials. According to the CARD data [27]; its share was an average of 59% of the total ethanol production cost (corn-based ethanol, dry-milling process for a representative Iowa corn ethanol plant) in the last 13 years (2007–2019). Therefore, it is important to be aware of how much corn can be harvested on a hectare. Figure 3 shows corn yields in China, the EU, and the USA from 2008 to 2018.

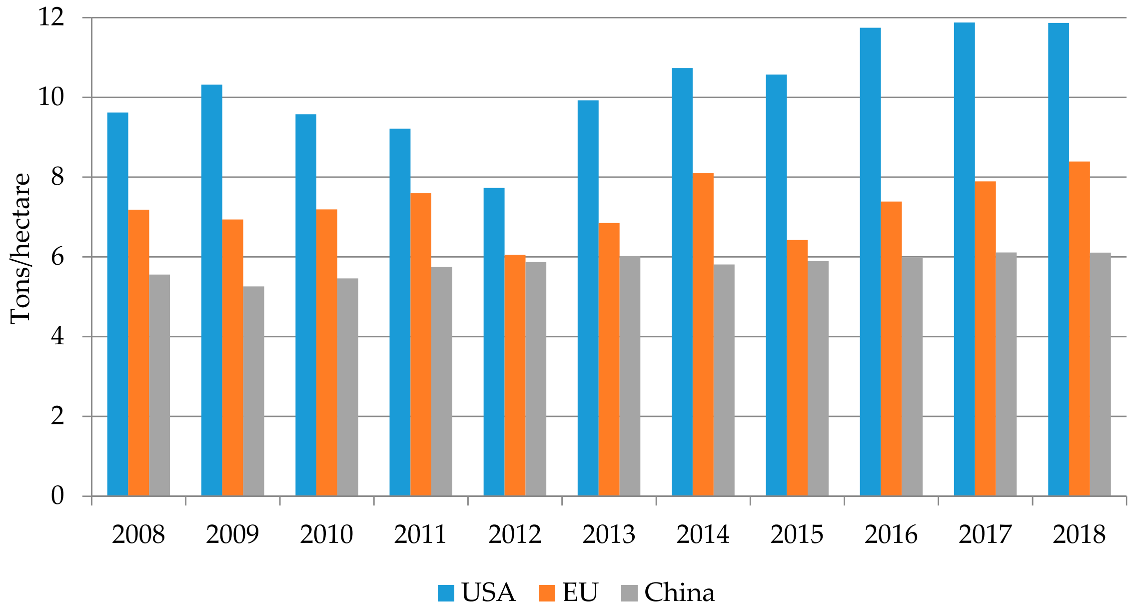

Figure 3. Maize yields. Source: Author's composition based on the Food and Agriculture Organization Corporate Statistical Database (FAOStat) [7].

As seen in the figure above, the USA enjoys extremely high corn yields which is on average 94% higher than the Chinese values and 41% higher than the yields in the EU. This, ceteris paribus, may result in American cost competitiveness over the major corn-based ethanol producers. Overall, commodity yields show an increasing trend; therefore, ethanol production costs are expected to be lower in the future. This is further strengthened by the fact that the maize production area increased by 20% during the analyzed period [7]. However, ethanol is only one pillar of the total demand besides the food and feed purposes.

3.3.2. Biodiesel Production

In the case of biodiesel production, oil can be extracted by cold and hot press extraction and additional transesterification processes. Large-scale production uses only the latter due to the much higher amount of oil. The efficiency of cold crushers is about 80% while hot press extraction (hexane crusher process) is 99% [28]. The remaining seed parts can be used for feeding, and their oil content depends on which extraction method was used. The meal has almost no oil content in the case of the hot extraction.

Production costs vary among the countries. Brazil is again the most cost-efficient producer in the world based on the lower boundary; however, the gap between the biodiesel production costs is narrower compared to ethanol. Despite its lower oil content (only 18%), soybeans are mostly used for biodiesel production in Brazil, because the remaining meal can be easily exported or used for feeding purposes [29]. Soybean is also the major raw material of biodiesel production in the USA, where significant genetic engineering occurred, in order to increase both the yields and oil content. In order to comply with biodiesel standards, rapeseed mostly is used in Europe. Table 4 contains the production costs of biodiesel in the major producer countries.

Table 4. Production cost of the major biodiesel producers (large plants).

Countries	USD/Liter	Weighted USD/Liter *
Brazil	0.67–0.90	0.73–0.98
USA	0.70–0.79	0.76–0.86
EU	0.79–0.87	0.86–0.95

* Weighting takes into account the lower energy content of biodiesel which is about 90% of the petroleum [23]. Source: Author's composition based on References [24,30].

Biodiesel production costs are much higher than that of ethanol, neither Brazil nor the USA can produce biodiesel at a lower cost than oil. This means that without additional support, tax credit or blending mandate, it would not be profitable to produce biodiesel. The high cost of biodiesel production relates to low reactor efficiency and material/energy loss during the process [31]. According to the CARD [32] data from the last 13 years (2007–2019), its share was an average of 75% of the total biodiesel production cost (soybean oil).This is the reason why biodiesel from used vegetable oil can be cheaper, as the raw material costs less than either soybean or rapeseed. Figure 4 explains why soybean is used on the American continents and why rapeseed is a more common raw material in the EU.

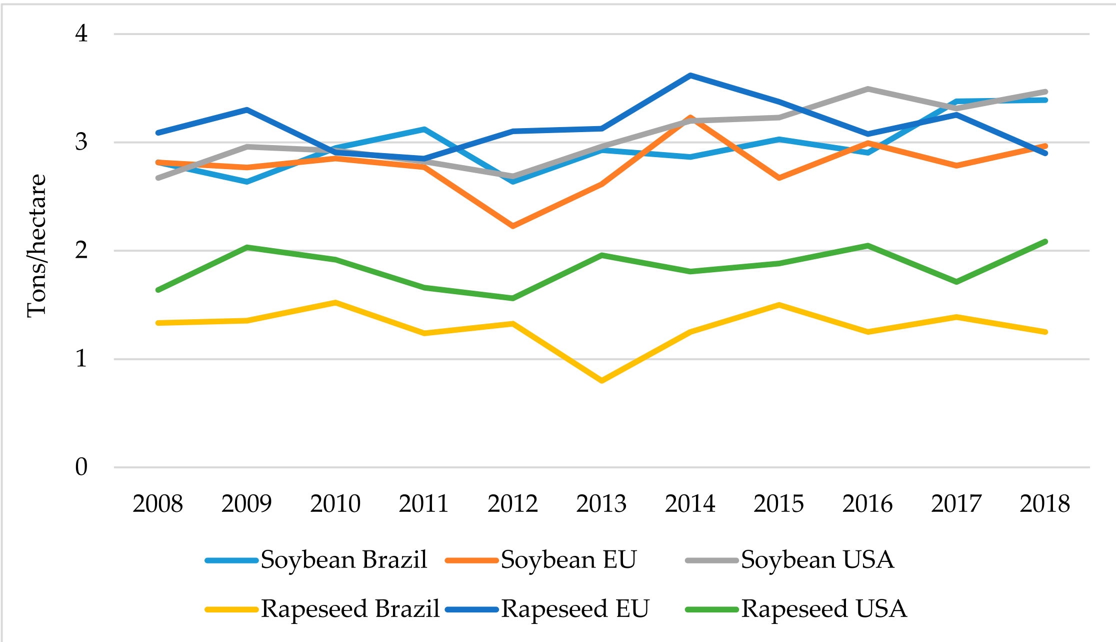

Figure 4. Soybean and rapeseed yields. Source: Author's composition based on FAOStat [7].

The EU is not self-sufficient in soybean production; it experiences slightly lower yields (e.g., an average of 10.2% compared to the USA). However, rapeseed production is more efficient in the EU compared to either Brazil or the USA, as the EU enjoyed 149.8% and 72.0% higher average yields over the analyzed period, respectively. The yields of biodiesel raw materials also show an increasing trend resulting in lower productions costs. Regarding biodiesel, the cost of raw materials is the most important concern; higher yields result in lower production costs compared to the ethanol production.

3.4. Biofuel Regulations and Their Implications

Pure biofuels are rarely used, they are mostly blended with conventional fuels. There is no doubt that policy measures are the major drivers of both production and the use of biofuels [33]. The blending mandates have the most significant impact on the use of biofuels, higher percentages of blending mandates result in the higher use of biofuels. In most cases, mandates are strengthened by different tax incentives, such as tax credits or tax exemptions.

As it was already demonstrated, the USA is the major producer in the ethanol market. Although the country has not signed the Kyoto Protocol, it pays attention to the use of renewable energy. The Renewable Fuel Standard (RFS) program was introduced in 2006 and provides a stable raw material basis for the ethanol blending mandates. This has had a significant impact on the maize market, as almost 40% of the national production is used for ethanol production, even over the last couple of years (Figure 5).

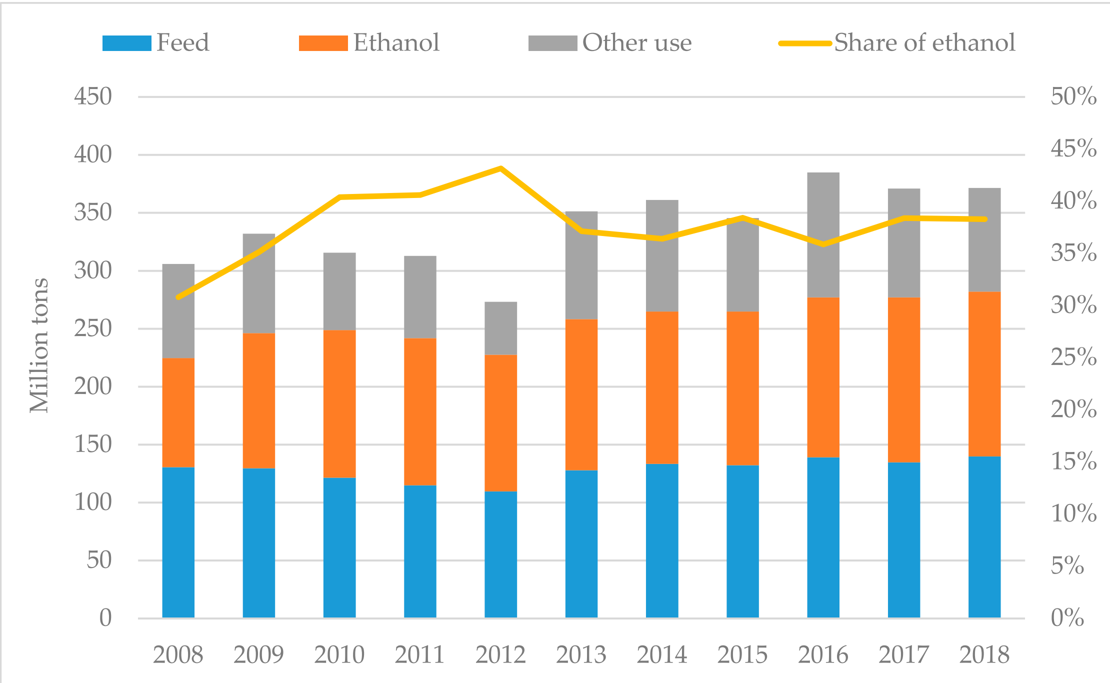

Figure 5. US maize use, 2008–2018. Source: Author's composition based on the United States Department of Energy, Alternative Fuels Data Center (USDE) data [8].

The use of corn to produce ethanol had its highest share in 2012, when it reached 43% of the total corn use, mostly at the expense of feed use. In the past years, ethanol and feed use had approximately an equal share in the maize utilization.

Blending rates vary across countries. However, it is generally accepted that ethanol can be blended with fuel up to a 10% ratio [34]. Ethanol use is significantly supported in Brazil. It has the highest blending rate at 18% to 27.5%, tax incentives for ethanol-flex fuel vehicles and a 16% average tax for ethanol, compared to that of 26.8% on gasoline [35]. In the United States, the use of E10 is common; however, E15 has already been approved and introduced in some states. The expanded version of the renewable fuel standard increased the blending mandate to 36 billion gallons annually by 2022, of which 15 billion gallons will consist of corn-based ethanol [36]. This results in ethanol taking an important role in the development of US biofuel use. Higher mandates of the RFS directly contributed to lower farm price volatility. This also encouraged further investments because of higher and predictable demand. Higher ethanol content is planned for (e.g., E20 or E30), but this requires further actions from the automobile industry. Production of non-first generation ethanol is subsidized by higher tax incentives which is up to 1.01 USD/gallon compared to the 0.46 USD/gallon of the alcohol fuel tax credits [37]. In the European Union, Directive 2009/28/EC regulates the promotion of renewable energies with a target of 10% for transportation (EU 2020 strategy). Seven percent of the target can be first-generation biofuels while taking into account that the GHG savings should be at least 35% [23]. Clearly, this target cannot be achieved without biofuels. This explains why E5 has already replaced E0, but E10 is also available in some EU member states (e.g., Belgium, France, Germany). The introduction of E10 needs to be carefully planned and communicated, as many consumers opposed its use in Germany, mostly due to the food versus fuel debate and engine compatibility concerns [38]. There are significant differences among the member states regarding this debate. Larger states like Germany, France, and Italy had an average of 6.5%, 7.5%, and 7% maximum cap on crop-based ethanol, respectively, in 2018 [39].

Regarding biodiesel, blending mandates are also in use. Brazil has continuously increased the blending rates, up to 10% in 2019. Further research is aimed at testing the impacts of B15 [35]. As the share of diesel vehicles is almost negligible therefore blending mandates are regulated at the state level and, generally, B5 is in use [40]. The EU, with its share of diesel automobiles being the highest globally, is lagging behind with values similar to 6.5%, 7.7%, and 7% in Germany, France, and Italy, respectively [39]. The other countries, which this study did not analyze, normally have lower blending mandates. For example, in China, the blending rate was only 2.2% for ethanol and 0.6% for biodiesel in 2015 [41]. However, it should be noted that the majority of the biofuel producing countries have a scarcity of fossil energies; therefore, this substitution results in lower energy dependency. Eight percent of global cereal production and 12% of the total vegetable oil production were used to produce biofuels in 2012 [42].

The EU's regulation is based on the greenhouse gas emission savings which was set to a minimum of 35% until 2017 and increased to 50% (for installations starting operation before 5 October 2015 from 1 January 2018) and 60% (for installations starting operation after 5 October 2015) from 2018 (EU, 2015). These values are completely in line with that of the US values for advanced biofuels (50%) and cellulosic biofuels (60%) measured in life cycle GHG emission reduction [43]. Table 5 shows the default and typical GHG effects of the different biofuels.

Table 5. Greenhouse gas effects of the major biofuels.

Biofuel Production Pathway	Default GHG Emission Savings	Typical GHG Emission Savings
maize ethanol	49%	56%
sugar cane ethanol	71%	71%
rapeseed biodiesel	38%	45%
soybean biodiesel	31%	40%
waste/farmed wood ethanol	74%/70%	80%/76%
waste/farmed wood Fischer–Tropsch diesel	95%/93%	95%/93%

Source: Author's composition based on Annex IV in Reference [23].

As seen in the table above, sugarcane-based ethanol has the highest GHG emission savings among the selected first-generation biofuels. If the ambitious targets of the renewable energy directives (RED) are met, then the production of waste-based biofuels is expected to grow in the short term due to the fact of their high saving values. Cellulose- and algae-based production are possible future options. It can also be anticipated that more member states will follow Italy, where the use of advanced biofuels have been mandated since 2018 [39]. Nevertheless, even the European countries are lagging behind the USA, where non-first-generation biofuels (cellulosic, biomass-based diesel and advanced) were introduced in the frame of RFS as early as 2009 [44]. But it can also be observed based on the dataset of the Environmental Protection Agency that conventional (i.e., starch-based) biofuels will compose approximately two-thirds of the total renewable fuel production in the USA in 2022.

Advanced biofuel production technologies are more expensive at this moment. However, there are numerous research projects all over the world working to make these technologies more efficient and therefore cheaper. There are many options at every level of the production chain (raw materials, enzymes, technology, energy use, etc.).

4. Trade Related Aspects of the Biofuels

4.1. Ethanol Related Trade

Ethanol production has had dynamic growth in the last couple of years (Figure 1), particularly in the last 8 years; however, it increased more in Brazil than in the EU or USA (Table 6). As a matter of international trade in related raw materials and processed products, sugar cane export increased the most (more than 4 times higher in 2018 than in 2012). However, this can be explained by its relatively low export value, as most of the sugar cane is converted into either cane sugar or ethanol. According to Table 6, sugar cane was used mainly for ethanol production, as ethanol prices decreased less then sugar prices during the analyzed period [45,46]. It was the major driving force of the growth of the sugar cane-based Brazilian ethanol production and denatured ethyl alcohol export. The EU and the USA use mostly corn; however, adverse changes can be seen regarding their corn exports. While the EU allocated more corn to ethanol production, which decreased the corn export, the limited use of corn by the RFS in the USA and the growing American corn yields (see Figure 3) allowed one-third more corn exportation from 2012 to 2018.

Table 6. Change of ethanol production and its related commodities' export, 2012–2018.

	Brazil	EU	USA	World
Ethanol production	42.55%	21.29%	21.05%	31.58%
Corn	−23.66%	−20.13%	33.32%	9.99%
Sugar cane	689.11%	138.97%	−21.53%	413.84%
Cane sugar	−93.51%	−34.45%	−27.57%	−87.19%
Denatured ethyl alcohol	94.76%	−40.44%	−9.11%	−11.25%

Source: Author's calculation based on the World Integrated Trade Solution (WITS) data [9].

Comparing export to import gives a narrative of the countries' position related to the different products they produce (Table 7). Brazil has traditionally been a corn exporter, although on a smaller scale in 2016, when the weather was unfavorable. The country exported 30 times more corn than imported on an average. Brazil became an ethyl alcohol exporter as well. The EU imports more ethanol related commodities than it exports, especially regarding sugar cane. The USA also has a corn (as a major corn producer and exporter in the world) as well as a denatured ethyl alcohol surplus (28.52 to 535.15 times more exports than imports).

Table 7. Export/import ratio of ethanol related commodities, 2012–2018.

Country/Year	2012	2013	2014	2015	2016	2017	2018
Brazil							
Corn	31.44	39.46	33.80	112.23	7.52	21.90	27.39
Sugar cane	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cane sugar	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Denatured ethyl alcohol	0.00	0.09	0.10	1.70	0.52	25.79	10.59
EU							
Corn	0.84	0.76	0.70	0.79	0.71	0.65	0.58
Sugar cane	0.19	0.24	0.08	0.07	0.08	0.13	0.08
Cane sugar	0.14	0.27	0.53	0.18	0.24	0.26	0.27
Denatured ethyl alcohol	0.34	0.34	0.64	0.73	0.70	0.68	0.66
USA							
Corn	10.21	4.54	17.26	16.89	18.44	19.92	33.50
Sugar cane	0.22	0.11	0.12	0.16	0.30	0.10	0.07
Cane sugar	0.00	0.04	0.03	0.02	0.01	0.02	0.02
Denatured ethyl alcohol	28.72	55.44	37.80	49.32	535.15	50.08	44.87

Source: Author's calculation based on WITS data [9].

Correlation of the independent variables with the ethanol production was also calculated (Table 8). Sugar cane export was positively correlated with ethanol production in every case, which suggests that the exported sugar cane is converted mostly into ethanol in the destination country. Cane sugar is generally negatively correlated with ethanol production, as it is a final product and cannot be used for ethanol production. The value of corn exports has a negative relationship with ethanol production in Brazil and the EU, where it is used for ethanol production. A positive correlation can be observed regarding the USA and the rest of the world which also indicates that some part of the imported corn is also processed to ethanol. Denatured ethyl alcohol is generally negatively correlated with ethanol production; however, denaturation is meant to discourage human consumption.

Table 8. Correlations with the ethanol production.

	Brazil	EU	USA	World
Corn	−0.5227	−0.5091	0.6222	0.1104
Sugar cane	0.4626	0.3691	0.3018	0.6708
Cane sugar	−0.8017	−0.1890	−0.4610	−0.8665
Denatured ethyl alcohol	0.2586	−0.5047	−0.2541	−0.5626

Source: Author's calculation based on WITS data [9].

Before running the regression models, the study calculated the correlations among the independent variables. Detailed results can be found in Annex 1. Table 9 summarizes the country-level model results. The explanatory power of the models varied between 0.35 (EU) and 0.94 (USA); however, the explanatory power of the effective independent variables (adjusted multiple R^2) were much lower, except for the USA. According to the F and p statistics, all the model results were not significant even at the 10% level ($p < 0.1$). Although they were not significant, the results were mostly straightforward (Appendix A):

- Cane sugar export had a negative impact on ethanol production in Brazil;
- Corn export had a negative impact on ethanol production in the EU;

- Sugar cane and cane sugar export had a positive effect in the USA; however, none of them can be compared to the significance of corn exports;
- On the world level, corn and sugar cane exports had a positive impact on ethanol production, implicating that a percentage of their exports (0.1% for corn and almost 20% for sugar cane) are used for ethanol production, while cane sugar exports negatively influenced the global ethanol production.

Table 9. Major characteristics of the ethanol regression models.

	Multiple R^2	Multiple R^2 Adjusted	F	p
Brazil	0.6763	0.0288	1.0445	0.5427
EU	0.3465	0.0198	1.0605	0.4271
USA	0.9401	0.8203	7.8474	0.1162
World	0.8210	0.4629	2.2928	0.3260

Source: Author's calculation based on WITS data [9].

None of the abovementioned variables were significant at the 5% level, except corn on the world level ($p = 0.0122$).

4.2. Biodiesel Related Trade

Biodiesel production has rapidly increased in the last couple of years compared to ethanol production (Figure 2). This is shown in Table 10. On the world level, it increased almost 60% from 2012 to 2018, particularly in the USA (107.33%) and Brazil (97.99%). The most important conclusion from the table below is that the export of raw materials (soya bean, rape seed, and palm nuts) has generally increased, while the export of processed products (oils) decreased. The two exceptions were rape seed, which is produced mainly in the EU, and palm oil on the world level, but none of the analyzed countries were significant palm nut or palm oil producers.

Table 10. Change of biodiesel production and its related commodities' export, 2012–2018.

	Brazil	EU	USA	World
Biodiesel production	97.99%	22.65%	107.33%	59.09%
Soya beans	92.43%	−31.09%	−30.81%	12.93%
Rape or colza seeds	1838.31%	−25.94%	−23.28%	−11.56%
Palm nuts and kernels	N/A	−71.78%	1147.67%	13.77%
Soya-bean oil	−50.50%	−37.49%	−24.14%	−25.93%
Palm oil	−70.27%	−12.81%	−32.63%	31.40%
Rape, colza or mustard oil	−39.67%	−35.81%	−75.21%	−25.04%
Biodiesel	N/A	105.40%	−34.27%	55.01%

Source: Author's calculation based on WITS data [9].

Based on import–export data, Brazil is a significant supplier of soya beans and soya-bean oil to world markets (Table 11). The EU has a surplus in soya-bean and rape oil but has a deficit of raw materials (i.e., soya beans and rape seed). This is a clear sign of the higher value-added trade. The trade characteristics of the USA are similar to the Brazilian one; high level soya bean and soya-bean oil exports.

Table 11. Export/import ratio of biodiesel related commodities, 2012–2018.

Country/Year	2012	2013	2014	2015	2016	2017	2018
Brazil							
Soya beans	112.94	179.32	90.97	191.64	163.18	305.32	521.99
Rape or colza seeds	0.00	0.00	0.00	0.00	0.12	0.14	0.42
Palm nuts and kernels	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Soya-bean oil	1740.18	257.63	4018.12	70.21	20.18	24.83	40.64
Palm oil	0.28	0.31	0.43	0.59	0.20	0.45	0.14
Rape, colza or mustard oil	0.13	0.08	0.07	0.05	0.21	0.12	0.08
Biodiesel	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EU							
Soya beans	0.18	0.12	0.12	0.13	0.14	0.16	0.14
Rape or colza seeds	0.66	0.70	0.70	0.67	0.66	0.63	0.63
Palm nuts and kernels	0.35	0.68	0.40	0.30	0.18	0.28	0.23
Soya-bean oil	1.56	1.70	1.37	1.72	1.53	1.43	1.46
Palm oil	0.26	0.26	0.26	0.26	0.28	0.27	0.28
Rape, colza or mustard oil	1.17	1.38	1.16	1.27	1.29	1.20	1.06
Biodiesel	0.63	1.04	1.15	1.08	1.13	1.00	0.95
USA							
Soya beans	75.69	28.23	19.96	36.18	57.11	49.80	50.20
Rape or colza seeds	0.60	0.32	0.26	0.45	0.45	0.37	0.46
Palm nuts and kernels	0.06	0.68	0.67	1.71	3.38	5.03	0.57
Soya-bean oil	14.59	9.28	11.59	7.05	7.40	7.62	6.73
Palm oil	0.02	0.03	0.02	0.02	0.02	0.02	0.01
Rape, colza or mustard oil	0.20	0.09	0.07	0.07	0.07	0.05	0.06
Biodiesel	3.89	0.57	0.49	0.29	0.12	0.36	0.65

Source: Author's calculation based on WITS data [9].

Regarding correlations of the raw materials with the biodiesel production, most of the exportation of raw materials is positively correlated with production. This indicates again that some part of the raw material exports is processed into biodiesel in the importer countries. Negative values can be seen for the EU and the USA; however, the former is not self-sufficient in any of the raw materials, while the latter is a significant producer and exporter of soya beans. Rape seed is the dominant source of biodiesel production in the EU, and exporting it results in smaller available raw materials for biodiesel production, similarly to soya beans in the USA.

The export of processed products (different oils) is negatively correlated with biodiesel production on the country level, because they are sometimes used for different purposes other than biodiesel production (Table 12). Biodiesel exportation and production have a positive correlation on the world level which is an indicator of the rapidly growing production that allows higher export.

Table 12. Correlations with the biodiesel production.

	Brazil	EU	USA	World
Soya beans	0.8363	−0.6380	−0.6532	0.4645
Rape or colza seeds	0.8050	−0.6342	−0.4503	−0.3656
Palm nuts and kernels	−0.6175	−0.8706	0.3180	0.3392
Soya-bean oil	−0.6787	−0.7393	−0.4643	−0.8815
Palm oil	−0.6108	−0.4689	−0.3119	0.3103
Rape, colza or mustard oil	−0.8550	−0.7255	−0.6895	−0.7790
Biodiesel	−0.4556	0.8615	−0.3140	0.6739

Source: Author's calculation based on WITS data [9].

Table 13 summarizes the country-level model results for biodiesel regressions. Detailed results can be found in Annex 2. The explanatory power of the models was higher for biodiesel, varied between 0.53 (USA) and 0.97 (Brazil) with effective independent variables (high adjusted multiple R^2) for Brazil and the EU. The F and p statistics show that the EU model results were significant at the 5% level (p = 0.025) and the Brazil model was almost significant at the same level (p = 0.055).

Table 13. Major characteristics of the biodiesel regression models.

	Multiple R^2	Multiple R^2 Adjusted	F	p
Brazil	0.9721	0.9162	17.392	0.0551
EU	0.8425	0.7638	10.6990	0.02481
USA	0.5311	−0.4068	0.5662	0.7180
World	0.9123	0.4738	2.0805	0.4810

Source: Author's calculation based on WITS data [9].

According the detailed results, the generalized results of the country models are as follows (Appendix B):

- High multicollinearity among the independent variables decreased significantly the number of variables;
- None of the variables in any models were significant at the 5% level;
- Generally, the export of raw materials had a positive impact on biodiesel production, implying that some part of the imported raw materials is used for biodiesel manufacturing (0.02% for soya been, 0.1% for rape or colza seed, and 4.15% for palm nuts and kernels);
- The export of processed products (different oils) had a negative impact on production, as they are used for purposes other than biodiesel production;
- The majority of the coefficients were low, except for the export of palm nuts and kernels in the USA model; however, its export is always on the marginal level.

5. Discussion and Conclusions

The fossil energy resources of the Earth are finite; therefore, humanity must switch to the use of renewable energy sources. Biofuels are one of the long-term options. The present, first-generation technologies use mostly corn and sugarcane for ethanol production, and rapeseed and soybean for biodiesel production. The second-generation technologies are based on lignocellulosic materials, while further generations may use algae or even CO_2.

The global ethanol production is not only larger by volume, but also more concentrated compared to the biodiesel market. The USA itself accounts for half of the production, which goes up almost to 90% when combined with Brazil. Brazil is the most cost-effective producer; its sugarcane-based ethanol price is competitive with even the current cheap oil prices. Referring to biodiesel production, the EU has the highest market share, a bit above one-third, followed by the USA. However, their aggregate production accounts for less than 60% of the global market. Biodiesel cannot currently be produced profitably, as even the most effective producers have higher costs than the price of petroleum. However, it can be seen in the yields data that the analyzed countries use those raw materials which provide higher yields under the given climatic conditions (e.g., corn in the USA, soybean in Brazil or rapeseed in the EU).

The major driving factor behind biofuel usage is the blending mandate which is mostly accompanied by tax incentives. These rates vary between 5%–10%. The highest blending mandate is in Brazil (from 18% up to 27.5%). In the USA E10 is the most common, and almost 40% of the total corn production is used for ethanol production. The Renewable Fuel Standard set production targets of advanced biofuels, although their share is expected to reach only 50% of the conventional biofuels by 2022.

More attention should be paid to the greenhouse gas emission savings and the changes of the regulatory systems are encouraging this direction. The EU has increased its previous 35% target to 50% (old installations) and 60% (new installations), while the same values are in use in the USA (50% for advanced biofuels and 60% for cellulosic biofuels). These emission savings cannot be reached by most of the first-generation technologies. Therefore, waste-based and cellulose-based biofuel production should be increased in the short term, while algae-based production should be invested in for the future. However, their costs of production should be decreased in order to be competitive with the fossil substitute.

Regarding international trade, increasing the production of biofuels has resulted in decreasing (or less increasing) exports of the major raw materials (corn and sugar cane for ethanol and soya beans, rape seed and palm nuts for biodiesel). Higher yields were able to partly offset this phenomenon. On the processed product level (cane sugar for ethanol and different oils in case of biodiesel), this was further strengthened by another driving force: the price of the final products, especially for cane sugar. Its export value dropped by almost 90% from 2012 to 2018, caused mainly by the Brazilian decrease (−93.51%), where biorefineries could easily switch from sugar cane to either cane sugar or ethanol. Based on the import–export analysis, it became obvious that Brazil and the USA are more raw material abundant than the EU. The EU exports surpassed its import only for soya-bean oil and rape, colza or mustard oil. This indicates the intention of value-addition, as less raw materials and more processed products were exported.

Out of the eight regression models (country and world level), only the EU biodiesel model was shown to be significant at the 5% level, although their explanatory powers were high (from 0.35 to 0.94 for ethanol and from 0.53 to 0.97 for biodiesel). The exportation of corn and sugar cane had a generally negative impact on ethanol production. This effect was positive on world level, indicating that some of the imported raw materials are used for ethanol production. Cane sugar export had negative coefficient in the world model, simply because the sugar cane used for sugar production was taken away from ethanol production. The export of raw materials had a positive impact on biodiesel production, implying that some part of them were used for biodiesel production in the importer countries. The export of processed products (different oils) had a negative impact on biodiesel production, as they were normally used for other purposes.

To answer the research question, the increase of biofuel production was greater than the decrease of international trade of the analyzed raw materials. The most remarkable exception to this general conclusion was the USA, which was able to increase its ethanol production as well as its corn export (21.05% and 33.32%, respectively). The same pattern can be observed on the world level. Brazil played the same role on the biodiesel market, where biodiesel production and soybean export increased simultaneously (97.99% and 92.43% growth, respectively). The reasons behind that were the higher yields (21.71% for maize and 21.87% for soybean from 2012 to 2018 on the world level), and partly the larger harvested area (7.75% for maize and 18.56% for soybean) [6]. Although international biomass trade is likely to grow, the Sustainable Development Goals should be a guideline for growth [47]. It is important to note that the current production technologies have already reached high yields. This suggests that conventional biofuels will not be able to solve the growing transportation energy needs of the world and that humanity should find other solutions (e.g., further generations of biofuels or other types of renewable energies). However, an important step in this technology revolution process is the use of conventional (first-generation) biofuels.

Further research should be carried out on the connection between biofuel production and the related international trade. This is because the topic has scarcely been researched as well as the results being mostly non-significant so far. This may require augmented variables and the use of other statistical and econometric models. An expansion of the six-digit limit of the UN Comtrade international trade data would provide useful insights as to the influencing factors of the biofuel trade [48]. This expansion would lead to a more precise distinction of the biofuel-related data, as even the six-digit deep dataset sometimes contains different products (from the aspect of this research, for example, ethyl alcohol and other spirits, denatured; rape, colza or mustard oil or biodiesel and mixtures thereof, not containing or containing less than 70% by weight of petroleum oils or oils obtained from bituminous minerals). A more detailed analysis of the ethanol or the biodiesel chains could also be carried out. It would also be interesting to test more variables and/or combine them with a deeper trade analysis. Although the available biodiesel dataset (see Materials and Methods, Section 2) is limited at this moment, this analysis could be repeated later to verify the results of this study. Expanding the scope of the analysis to the other biofuel producing countries would be a logical continuation of this research.

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Appendix A

Table A1. Ethanol regression models in Brazil.

Brazil	Coefficient	Standard Error	t	p	R^2
Constant	28721	7909.9	3.631	0.0682	-
Corn	−0.0004	0.0017	−0.2453	0.8291	0.2732
Sugar cane	278.21	917.8	0.3031	0.7904	0.2145
Cane sugar	−0.2692	0.2187	−1.2307	0.3435	0.6428
Denatured ethyl alcohol and other spirits	0.0177	0.1064	0.1662	0.8833	0.0669

Source: Author's calculation based on WITS data [9].

Table A2. EU.

EU	Coefficient	Standard Error	t	*p*	R^2
Constant	6489.3	948.88	6.8389	0.0024	-
Corn	−0.0001	0.0002	−0.7495	0.4952	0.2592
Denatured ethyl alcohol and other spirits	−0.0015	0.0021	−0.7309	0.5053	0.2547

Sugar cane and cane sugar were excluded due to the high correlation. Source: Author's calculation based on WITS data [9].

Table A3. USA.

USA	Coefficient	Standard Error	t	*p*	R^2
Constant	61963	6674.7	9.2833	0.0114	-
Corn	0.0029	0.0006	4.8839	0.0395	0.3872
Sugar cane	2.9493	7.9704	0.3700	0.7469	0.0911
Cane sugar	9.3331	6.6026	1.4135	0.2931	0.2125
Denatured ethyl alcohol and other spirits	−0.0344	0.0100	−3.4272	0.0756	0.0646

Source: Author's calculation based on WITS data [9].

Table A4. World.

World	Coefficient	Standard Error	t	*p*	R^2
Constant	79372	48473	1.6374	0.2432	-
Corn	0.0013	0.0019	0.6857	0.5637	0.0122
Sugar cane	0.1981	0.3320	0.5966	0.6113	0.4500
Cane sugar	−0.0067	0.0060	−1.1174	0.3800	0.7509
Denatured ethyl alcohol and other spirits	−0.0122	0.0213	−0.5744	0.6237	0.3166

Source: Author's calculation based on WITS data [9].

Appendix B

Table A5. Biodiesel regression models in Brazil.

Brazil	Coefficient	Standard Error	t	*p*	R^2
Constant	2274.6	980.42	2.3200	0.1461	-
Soya beans	0.0001	0.00003	4.3620	0.0487	0.6994
Soya-bean oil	−0.0009	0.0003	−2.7294	0.1121	0.4607
Palm oil	0.0034	0.0063	0.5396	0.6435	0.3731
Biodiesel	−0.0271	0.0086	−3.1594	0.0873	0.2076

Rape or colza seeds and palm nuts and kernels were excluded due to the high number of missing data. Rape, colza and mustard oil were excluded due to the high correlation. Source: Author's calculation based on WITS data [9].

Table A6. EU.

EU	Coefficient	Standard Error	t	p	R^2
Constant	11973	1818	6.5859	0.0028	-
Rape or colza seeds	−0.0006	0.0004	−1.596	0.1857	0.4022
Biodiesel	0.0003	0.0001	3.3442	0.0287	0.7422

Soya beans, palm nuts and kernels, soya-bean oil, palm oil and rape, colza or mustard oil were excluded due to the high correlation. Source: Author's calculation based on WITS data [9].

Table A7. USA.

USA	Coefficient	Standard Error	t	p	R^2
Constant	11390	7408.1	1.5376	0.2640	-
Soya beans	−0.0003	0.0003	−1.1369	0.3734	0.4266
Palm nuts and kernels	2.7829	5.3874	0.5166	0.6569	0.1011
Soya-bean oil	0.0012	0.0096	0.1234	0.9131	0.2156
Biodiesel	−0.0017	0.0059	−0.2931	0.7971	0.0986

Rape or colza seeds, palm oil and rape, colza and mustard oil were excluded due to the high correlation. Source: Author's calculation based on WITS data [9].

Table A8. World.

World	Coefficient	Standard Error	t	p	R^2
Constant	75045	83522	0.8985	0.5340	-
Soya beans	0.0002	0.0016	0.1185	0.9249	0.2158
Rape or colza seeds	0.0010	0.0050	0.1898	0.8806	0.1337
Palm nuts and kernels	0.0415	0.0589	0.7059	0.6087	0.1151
Soya-bean oil	−0.0056	0.0053	−1.0562	0.4826	0.7770
Palm oil	−0.0004	0.0006	−0.7708	0.5819	0.0963

Biodiesel and rape, colza and mustard oil were excluded due to the high correlation. Source: Author's calculation based on WITS data [9].

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