UNIVERSITY OF PIRAEUS
DEPARTMENT OF INTERNATION AND EUROPEAN STUDIES

MSc in ENERGY: Strategy, Law & Economics

Master Thesis

Biofuels: Technology transition and geopolitics

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Submitted in: 20/07/2022

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Acknowledgements
The whole course of this master program was an inspiring and mind-opening experience, despite the challenging and hard times that there have undoubtedly been a few. The brief but multi-disciplinary curriculum and the similarly multidisciplinary synthesis of the classmates, professors and supporters of the program have given new dimensions in my perception and subsequently in my professional career in the energy sector that was mostly based to my more technical background. Therefore, the first to thank, are all professors and fellow classmates that have been instrumental in such a productive and intriguing journey.

I would like to thank separately Dr. Athanassios Platias that through his lectures in the second semester was the inspiration to further study the field of geopolitics and deepened my grasp of it; Dr. Spyridon Roukanas for setting the foundations on macroeconomy and gave me such valuable tools not just for the completion of this thesis but also for further studying and understanding of the geopolitical facets of energy and not only that; and finally, Dr. Ioannis Paravantis for intriguing us during the entire master's program, and supporting me during the preparation of this study, with his invaluable guidance which gave me the impetus to conduct research on the topic of biofuels as well as his directions and his constructive criticism.

Last but not least I want to express my gratitude to my family and my close friends for being there for me through the entire journey, with their presence and their patience in each circumstance. Without them I would not be in this position, and without their psychological support this thesis would not have been realized.

Abstract
In the current era there is a shift in the energy landscape that favors alternative technologies over fossil fuels. Biofuel is such a technology that is reclaiming importance with its major products being biodiesel and bioethanol. From the outset, the sector had a number of state stakeholders, but it has since grown notably in the last few decades. The choice of the production, the investment in this technology and the development rate for each state is different and is affected by a unique combination of geopolitical factors.

The aim of this thesis is to provide an overview of the complex geostrategic energy map formed in this transitional moment, by clarifying these factors and providing a qualitative study on how each of them affects the states. In order to accomplish this scope, a number of factors were identified in the literature, along with their geopolitical impact. Energy security was recognized as one of the most significant drivers for the states, as also their commitment to combating climate change. Another advantageous feature is rural and economic growth as well as the potential for a more sustainable development. On the other hand, factors that limit the growth of the sector include environmental concerns about the farming practices, deforestation to make more land available for biofuels, or competition with the food sector that results in higher food costs and food insecurity. In the case studies that followed, their impact on important producers – particularly Brazil, the EU, the US, China, Malaysia, Indonesia, and Thailand – was clarified. Countries such as US, which leads the production since 2006, and Brazil, the previous leader, have developed an industry that harvests in a balanced manner the majority of the advantages to support their climate strategy, their energy security, and their rural sector, while being little affected by negative impacts, as Brazil has some concerns about deforestation and food prices. Other states, have more direct priorities such as EU, which as the largest importer has taken a regulatory role, and China, with its enormous energy needs, utilize the sector primarily to strengthen their energy security before achieving their environmental goals. Finally, Malaysia, Indonesia and Thailand provide an excellent comparison. The first two have developed export strategies to support their economic and rural development, while Thailand has a completely introverted profile in this industry and is working to achieve a more environmentally conscious and sustainable development, risking losing its competitiveness in the process. Therefore, it is made clear that although all factors are generally applicable to all regions, they have a different specific gravity for each player.

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Chapter 1: Introduction

1.1 Preamble

We live in an era when an energy shift is happening. Despite the fact that fossil fuels still control the majority of the energy market, it cannot be denied that other, more environmentally friendly technologies, transitional or not, are gaining ground on them Additionally, as governments throughout the world sign treaties to combat climate change and as the issue becomes more urgent by the day, other forms of energy will increase their market share. Although it appears that wind and solar have reached a mature stage where they can replace a sizable amount of the coal and other fossil fuels used to provide electricity into the grid, they are not yet the best option for the transportation and mobility sector.

Among the other contenders to challenge the dominance of oil products in this sector such as hydrogen, electricity and biofuels, only the latter is available for use by the existing infrastructure and requires little to no investment. This gives a great advantage to the technology of biofuels, particularly the two major biodiesel and bioethanol in terms of their application. However, a range of geopolitical factors have an impact on their production, and as a result, their level of acceptance varies. Each country has a variety of incentives to invest in their development instead of other forms, while also a different set of drivers opposed to their expansion. Under these circumstances, a complex economic and geostrategic map is created, allowing for both synergies and competitions to develop among the major producing states.

The aim of this thesis is to identify the driving factors of the biofuel industry, and based on them to describe how each of them affects each one of these important players, in order to offer an overview and a better understanding of this complex geostrategic map.

1.2 Structure of thesis

This thesis is organized in the following five chapters:

In “Chapter 1”, there is the introduction to the topic of the thesis, its purpose and its structure. Next, in “Chapter 2”, under the guidance of the literature, biofuels will be introduced while also there will be presented the course of their development up to date. Then, the major factors advancing and opposing their development will be identified and discussed as they are met in the literature. “Chapter 3” summarizes the scope of this study, setting also the course of the analysis and the methodology followed through this analysis. Then, “Chapter 4” being the major analytical part, hosts a detailed report of the findings of the conducted research and a discussion in relation to these findings. The study is summarized in "Chapter 5", adding thoughts on the limitations presented in this thesis, and suggestions for additional research on the topic.

Chapter 2: Literature review

2.1 Introduction

This chapter will be the introductory into the world of biofuels. They will be presented as counterpart of the fossil fuels, with qualitative comparisons of their technical features and their course from the beginning as based on the literature. In this course the key biofuels will be discussed as well as their four main generations, according to the processes and feedstock used for their production. The advantages and disadvantages of each will then be explored from the viewpoint of the current period, which is regarded as transitory in the energy sector and is therefore unstable despite having a definite tendency toward decarbonization. In order to provide the context for the study that will follow, the major geopolitical driving forces will then be identified in the literature and further examined. Finally, there will be an attempt to classify the literature met on the subject to be later used as guidance and tool for the analysis.

2.2 Biofuels

A different type of renewable energy that can be used as a fuel for transportation is biofuel. It is produced from biomass through contemporary processes that resemble the geological processes, which created fossil fuels, but in an accelerated form. The phrases biofuel and biomass are sometimes used interchangeably since biomass can also be used directly as fuel. A more technical definition found in literature is that *"... the term biofuel is referred to as liquid or gaseous fuels for the transport sector that are predominantly produced from biomass."*[1].

Biofuels, like conventional fossil fuels comprise also of hydrocarbons. However, as their feedstock is biomass the carbon dioxide (CO_2) that they emit into the atmosphere when burned, is the carbon absorbed by the plant mass when it was growing through the photosynthetic process – a solar powered process[2]. Thus, biofuels recycle the carbon they emit and due to their much shorter carbon cycle -comparing to fossil fuels – they are renewable and regarded as being significantly less polluting in terms of greenhouse gases (GHGs), if not a carbon-neutral renewable energy source.

Liquid biofuels can be an alternative fuel for the conventional internal combustion engines requiring minor or no modifications at all. Transport vehicles that nowadays use crude oil derived fuels such as diesel, gasoline, or kerosene to move in the land, air and sea can run instead on liquid biofuels, mainly bioethanol and biodiesel, decreasing pollutant emissions by a vast sum in the sector of transportation[3]. By enabling the energy transition to a future that is more sustainable and renewable, their technology helps to mitigate climate change.

In comparison to other more competitive renewables, such as wind and solar power, they still have the advantage in the transport sector as they are ready to be used, utilizing the existing infrastructure[4]. Wind and solar technology may be currently more advanced and developed at a stage that they can provide substantial amounts of electricity in the power grids, however, the

[1] Demirbas, A. (2007)
[2] Aro, E. (2015)
[3] Kandasamy, S. et. al. (2021)
[4] Brutschin, E., & Fleig, A. (2018)

infrastructure currently in place for the fossil fuels is ready to be used with low blends of biofuels (5-10%) and with slight modifications it can be used even with pure biofuels. It is also stated that, *"The road map of renewable energy indicates that liquid biofuels, together with both current and highly developed forms of ethanol and biodiesel, may be expected to contribute about 10% of the transportation energy requirement by 2030, three times higher than in 2017."* [5].

Moreover, the aforementioned technologies are directly converting wind and sun to electricity, thus require electrification of the mobility. However, this electrification is still hindered by the technological barrier of the energy storage. Although this issue is getting gradually solved for land vehicles, with the advances in the technology of batteries, it is still a thorn in the shipping and the aviation that account for 20% of the energy use in the transport sector[6].

Biofuels as fossil fuels can be met in several different forms of products. From long chain heavy and dense ones like biodiesel, to the one carbon molecule methane biogas or even biohydrogen. The most known forms of biofuels are bio-oil or vegetable oil, biodiesel, biogas, syngas, bio-ethers and the alcohols, biomethanol and bioethanol. Even solid mass made from pressurized waste material that consists of fatty and woody content is considered to be a form of biofuel.

However, as shown in Figure 1 the major biofuels produced and used in the modern transportation sector are just two: bioethanol and biodiesel. Figure 1 also presents the most common feedstock used for each of these two biofuels, although more information will be provided in the paragraphs that follow. An interesting fact is that each state production is mainly focused in one of these two types of biofuels. *"Bioethanol constitutes above 80% of the liquid biofuels in United States, Brazil, Canada, Australia, and China, while biodiesel accounts for more than 60% in European countries (except for Britain)."* [7].

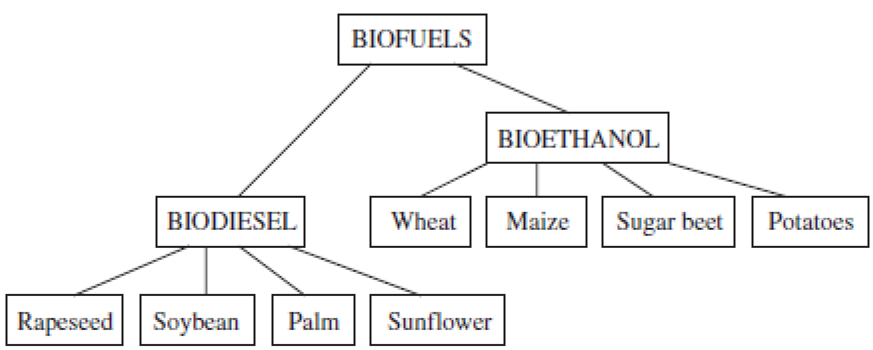

Figure 1 Resources of main liquid biofuels for automotive.[8]

[5] Brutschin, E., & Fleig, A. (2018)
[6] Kandasamy, S. et. al. (2021)
[7] Azadi, P. et. al. (2017)
[8] Demirbas, A. (2007)

2.2.1 Biodiesel

Biodiesel is the renewable alternative fuel of the conventional diesel fuel, far less polluting though. It is also referred as vegetable oil (m)ethyl esters, and as this name suggests it derives from transesterified vegetable oil[9]. It has a lower power output and energy content of almost 8% compared to conventional diesel, however, it displays improved ignition characteristics having a higher cetane number and lower sulfuric content that results to cleaner exhaust gases[10].

The transesterification happens when mixing alcohols with vegetable-oil in an environment of high pressure and temperature. Biodiesel can be produced from various oil feedstock, such as animal fat (poultry, beef and pork), natural oils from soybean, canola, corn, palm, Jatropha or from seeds like rapeseed, sunflower, cottonseed and mustard seed, even waste cooking oils and greases[11].

According to EERE "*Biodiesel can be blended and used in many different concentrations. The most common are B5 (up to 5% biodiesel) and B20 (6% to 20% biodiesel)* [12]*. B100 (pure biodiesel) is typically used as a blendstock to produce lower blends and is rarely used as a transportation fuel."* Based on the regulations, B5 and B20 blends can be used interchangeably in the existing diesel engines requiring no modifications. Furthermore, the power and energy content are only slightly compromised by 1-2%, while the emissions of carbon dioxide are reduced by 15% in comparison with diesel[13] and it can offer a slightly better fuel economy. Pure biodiesel (B100), on the other hand, can reduce GHGs emissions by a whole 74% compared to conventional diesel[14], however, it is not so wide-spread due to the modifications it requires to be used in modern diesel engines, its 8% reduced energy content and lack of regulatory incentives in the market.

2.2.2 Bioethanol

Bioethanol is the other widely used type of biofuel, which is interchangeable with petrol. It is produced out of a wide range of carbohydrate sources, through alcoholic fermentation of sugars. Such sugars can be found in biomass feedstock, which includes agricultural goods like (wheat, sugar beet, corn, straw, and wood), as well as domestic bio-waste and sugars that are created through the catalytic hydrolysis of cellulose and hemicelluloses found in plant tissue. The energy content of bioethanol is roughly 33% lower than that of pure gasoline, and the effectiveness of the fuel relies on the other additives used.

It is most usually utilized as a petrol additive/substitute[15], that can be used in different percentages of blends with petrol. Based on the EU quality standard (EN 228), it can be blended up to 5% with petrol (E5) and used in unmodified conventional petrol engines without voiding any warranties, while according to EIA the respective percentage in U.S. is 10% (E10). Other common blends, such E15 and E85 (with a 15% and 85% bioethanol content respectively), can be used in engines that have been specially built or modified.

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[9] Demirbas, A. (2007)
[10] McCarthy, P. et. al. (2011)
[11] Ditzel, K. et. al. (2018)
[12] U.S. DOE, EERE "Biodiesel Blends." | https://afdc.energy.gov/fuels/biodiesel_blends.html
[13] U.S. DOE, EERE (2017) "Biodiesel Basics."
[14] U.S. DOE EERE (2018) "Biodiesel Benefits and Considerations."
[15] Demirbas, A. (2007)

2.3 Biofuels generations

A second classification of biofuels is according to the type of feedstock used for their production. Based on this aspect biofuels can be classified in four generations. The first one is directly related to edible biomass, while the second is mostly based on non-edible one. The feedstock of the third generation is algae cultivated in water environments, lessening the significance of the land role. The fourth generation is based on genetic modified algae and microorganisms that produce biofuels as byproducts of their life cycle rather than serving as the feedstock itself. The four generations will be covered in greater detail in the following sections.

As was previously noted, first-generation biofuels are now the most developed technology thus the most widely produced and utilized. This is the reason that they are also called conventional biofuels. Their feedstock is cellulose, sugars and oils, found from food crops like corn, wheat, sugarcane, canola-, palm- and soybean- oil, that are converted to biofuels through fermentation followed by distillation when producing bioethanol, or transesterification of oils and animal fat when biodiesel is the final product. Their technology is considered simple and mature, while also cost competitive to fossil fuels, and this is why there are already applied in several countries with US and Brazil in the forefront of production[16].

2.3.1 First generation

The introduction of the first generation of biofuels opened up new possibilities for reducing greenhouse gas emissions and promoting greener mobility. These biofuels also supported agricultural output, generated new employment opportunities, and strengthened many rural communities. However, as a first step, several drawbacks are also identified in this technology with the first and most significant, the connection between the fuel and the food products which in previous years significantly increased food prices and stimulated *"large-scale land transactions that deprive local communities of the land and water necessary to grow food"*[17]. The issue is more intense in regions with inadequate food production to feed the population like Sub Saharan Africa, but even where food deprivations is a result of unequal distribution of food supplies such as the region of South Asia[18]. Furthermore, issues about harmful results in biodiversity have emerged as significant arable areas are dedicated to biofuels and as forest areas are being cleared for such crops.

2.3.2 Second generation

The feedstock of the second-generation biofuels is non-edible biomass, comprised of non-edible parts of crops - such as husks, leaves, stems and wood - food and organic waste, and non-edible, fast growing, bioenergy crops - such as jatropha and switchgrass[19]. This kind of cellulosic biomass has to be pretreated biochemically or thermochemically in order to free the sugars that lay in the plant fibers, and come in the stage of the first-generation feedstock – ready for fermentation and distillation.

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[16] U.S. DOE, EERE "Biodiesel Blends."
[17] Gonzalez, C. G. (2018)
[18] Hazell, P., & Wood, S. (2007)
[19] Gonzalez, C. G. (2018)

The second-generation biofuels came to address several of the issues met with the first-generation ones. Several of the second-generation crops are more durable and can withstand harsher environments and conditions like draughts soil deprived lands and extreme temperatures. Thus, they can be cultivated in marginal lands where food crops could not, and in this way, they would not compete for resources with food production. Although this is possible, even these crops do not thrive in such lands and offer reduced productions when deprived of water and nutrients. Thus, even though second-generation biofuels are not derived from food and they can grow in marginal soil, some may be grown on land that could be used to cultivate food, resulting in indirect competition between fuel and food. The use of forest land and forest biomass (deforestation) may also cause additional issues.[20].

Their technology is in the process of maturing, both in terms of its development and its economic impact, as a result of the years' worth of money that have been put into this generation. Several steps are still to be made in order to reach maturity, such as technological and legislative advances in new breeding techniques and allowance of new productions that will facilitate the preprocess steps and offer more efficient, productive and better-quality crops[21,22]. Cellulosic sources can be employed at this stage and do allow for commercial production, but the additional preparation steps increase complexity, demand for energy, and cost. In order to compete with the first generation and conventional fuels, second generation biofuels still require further subsidies

2.3.3 Third generation

The biofuels of the third generation involve production that use algae as its feedstock. Algae captures carbon dioxide through a photosynthetic process when cultivated and creating biomass[23]. It can also be cultivated in waste water, or seawater thus its cultivation media completely removes the need of arable land and the competition with the food production, not even for resources such as water that algae may require in significant amounts. Biofuels can be produced from algae utilizing processed fairly similar to the ones of the first generation. However, their production could become much denser (10 and up to 100 times more biofuel per acre than other land crops)[24]. Therefore, though still in their early stages, slow development and the fact that they still involve costly processes, third generation biofuels have attracted great interest all over the world as one of the most promising alternatives. In the last decade, third generation biofuels have met the market and lately they attracted the interest of colossal energy companies such as ExxonMobil.

2.3.4 Fourth generation

Finally, the fourth generation suggests a completely different approach. Instead of creating biomass to be converted to biofuels, it uses genetically modified biomass to directly synthesize biofuels, through photosynthesis or electrosynthesis. This could reach even higher yield through a

[20] Gonzalez, C. G. (2018)
[21] EASAC Statement on new breeding techniques
[22] European Plant Science Organization, "Crop Genetic Improvement Technologies." (2015, February 26).
[23] Aro, E. (2015)
[24] U.S. DOE, EERE (2020) “Algal Biofuels.”

more efficient process; however, it requires high initial investments as it is still in the infant stages[25].

As only first and second generations account for the production of over 95% of biofuels globally, in this thesis these two technologies will be discussed.

2.4 Biofuel benefits and drawbacks

Summarizing the various aspects of biofuels, it is easily conceivable that there are different factors in favor of and against their development and utilization. Their first and most important advantage it their capability to reduce the GHGs emissions compared to conventional fossil fuels. In this way, they are counted as a more renewable energy source in the global attempt to limit the temperature rise below 2^{o}C or even 1.5^{o}C and tackle the issue of climate change. Biofuels are an important component of the solution at this crucial moment, when the catastrophic effects of global warming are becoming more and more evident and states are calling for commitment to faster and further emission reductions. They can be used as a direct replacement for fossil fuel products, utilizing the existent infrastructure and being adopted rapidly. This is more obvious in the transport sector where other renewable energy options are still in more immature stages.

Furthermore, biofuels as most of the renewable energy sources, are more evenly spread around the world[26]. The capability of every state to build and maintain their own production of renewable fuels can strengthen energy consumer states and regions that were previously deprived of fossil energy resources, therefore heavily dependent on oil. Producing states. Even if the capacity of a state's biofuel production cannot cover its fuel needs it would reduce its dependency. Thus, biofuel production could potentially lead to an improved energy security for the state, strengthening all of the four As[27]: Availability as more fuel will be available, accessibility as it can be cultivated decentralized, therefore close to the user needs, acceptability (that introduces the environmental factor) as it is a much cleaner renewable option instead of conventional fuels, and even affordability in periods of oil crisis, or as the biofuel technology advances and eventually would be able to offer a more price competitive product.

On the other hand, several issues have risen as biofuels are developing and their production is spreading around the world. The most significant out of them is as it was mentioned above the direct connection of fuel and food prices as too competitive products. This happens as the two first generations of biofuels are still the most wide-spread and it may hopefully fade out as the technologies of third and fourth generation will gain traction. Until then different legislations and regulations will have to deal with the issue as in poorer developing countries with vast croplands but also similarly high populations the food supply may not suffice to feed them all due to the rising price of food[28]. Another equally important issue is the threatening of biodiversity, as the

[25] Aro, E. (2015)
[26] Vakulchuk, R. et. al. (2020)
[27] Paravantis, J. A. et. al. (2018)
[28] Brutschin, E., & Fleig, A. (2018)

need for biofuels production lands leads to vast areas of deforestations, soil deprivation and water pollution and depletion[29]. A typical example could be the deforestations of the tropical forests of Indonesia so that they could be replaced by monocultural oil palm plantations. There not only the flora biodiversity was destroyed but also various fauna species were threatened with extinction.

Another issue that still exists but will be improved as biofuels technology advances, is their non-competitive price. Even in the most technologically advanced biofuel producing nations, like the US and Brazil, state subsidies are still necessary for biofuels to be cost-competitive with fossil fuels. This fact might alter if oil prices increase or if there is an oil crisis, but as long as oil products are still being produced, biofuels will continue to command a premium price.

Finally, the shift to renewable energy will cause governments that were once dominant due to their abundant fossil resources, particularly the petroleum states that focused all of their development on the extraction sector, to experience significant losses in wealth and influence.[30]. This may lead to increases conflicts in such regions even if biofuels could also improve the whole regions' energy security.

Another statement that should be taken as a fact is that the expansion of biofuels as also other renewables will change the energy supply–demand balance[31]. As a result, the global power dynamics will change accordingly. The adoption of the states and their movement in the shifting energy landscape will determine whether this results in new emerging powers or the same power in a modified energy market.

2.5 Progress through the years

Biofuels may have seen a rise in the recent decades; however, they are first met as technology much earlier, maybe even earlier than fossil fuels in the internal combustion engines. Indeed, the first invented internal combustion engines - 1826 by Samuel Morey and 1860 by Nicholas Otto - were designed to run on mixtures of ethanol[32, 33]. On the other side, vegetable oils and animal fat were the first alternative of whale oil used for lighting in 1818, but "*…the term "biodiesel" was first coined in 1988"*[34] and firstly used in the diesel engine in 1900 as a product of peanut oil. Afterwards, they were pushed aside by the use of cheaper fossil fuel products and taxation on ethanol that was in place in these periods as it had also other uses. But the two World Wars, and especially WW II led to oil shortages to several states around the world, and revived the use of biofuels mixtures, with Brazil's and U.S. production derived from corn, while Germany's was based on potatoes and U.K.'s on grain.

[29] Smith, J. (2010)
[30] Vakulchuk, R. et. al. (2020)
[31] Vakulchuk, R. et. al. (2020)
[32] Songstad, D. D. et. al. (2009)
[33] Albers, S. C. et. al. (2016)
[34] Wang, R. (1988)

Again, the following years, made biofuels irrelevant as they could not compete with the cheap oil flow from Middle East and the countries of Gulf. The resurrection came again globally with the more recent fuel shortages in the 1970's. There were the main crises in 1973 with the oil embargo by OPEC and the 1979 oil crisis that followed the Iranian War. Last but not least another great oil price shock came with the Gulf War in the early 1990's. During this period several oil consuming states were found under pressure and created biofuel programs to fuel their transportation in an alternative way. The most noted were, the Brazilian biofuels program PROÁLCOOL (National Alcohol Program), an ethanol program created on November 14, 1975[35], and the respective *"U.S. corn-based ethanol program at almost the same time but at a smaller scale than Brazil"*[36]. Other countries also designed similar programs, such as Germany, Kenya and China with less success. Also, Brazil's biodiesel program *"PROÓLEO (National Biodiesel Program), created in 1980 did not survive the drop of oil prices in the next years"*[37].

Oil prices are tightly corelated to the advance of biofuels in investment and production in literature[38, 39] as it will be analyzed in the next chapters. Nevertheless, except oil crises and fuel shortages other factors lead the development of biofuels as well. Economic and geopolitical factors, such as energy supply and energy security, climate change and renewable production, or even resource diversification and support or rural areas lead different states and regions to approach the field of biofuels from various angles and implement different programs. As an example, *"USA is a top producer of soybean oil, whereas Europe produces large amounts of canola oil, and this essentially determines which oil is used for biodiesel within these geographies."*[40]. Geopolitical power balances have changed over time and continue to change, and this will be the focus of this study.

2.6 Technology transition

The current era can be characterized by instability in the energy sector and the energy transition is oncoming. An energy transition where the oil sector is losing ground to the various forms of renewable energy.

The climate change and the effects of global warming are now apparent. As previously indicated, this forces an increasing number of nations to commit to combating it by moving toward decarbonization. In this way, renewables gain an even larger share in this energy transition.

At the same time geopolitical instability is also imminent, and the Ukrainian crisis have made it more exacerbated and evident than ever before. It is a crisis that has isolated vast amounts of resources (energy, mineral and food resources) from the global economy. A crisis that involves

[35] De Oliveira, F. C., & Coelho, S. T. (2017)
[36] Timilsina, G. R., & Shrestha, A. (2010)
[37] Albers, S. C. et. al. (2016)
[38] Brutschin, E. et. al. (2018)
[39] Azadi, P. et. al. (2017)
[40] Songstad, D. D. et. al. (2009)

some of the major oil suppliers such as US, Russia and Ukraine and thus results to even greater volatility to the oil prices that have skyrocketed, causing immense economic and geopolitical risks.

In this framework, biofuels have the potential to reemerge into the forefront. According to what was stated in the preceding paragraphs, they always attracted interest and investments during such periods of oil instability since they can replace sizable quantities of oil products. And there is tremendous need particularly in the transportation and the mobility sector, which is on an upward trend with increasing demands, rebounding after the period of Covid-19 pandemic.

Moreover, biofuels are a sustainable green solution – due to their carbon neutrality – that also offers a new geostrategic perspective. In contrast to other technologies, they require resources that are available in most parts of the world, as their feedstock can be cultivated not only in tropical but also in milder and more temperate climates, in temperatures that can be found in the majority of the world's zones. Last but not least, utilizing the existing infrastructure, they can be stored and transferred from their producing location to the consuming one. This offers a great advantage compared to wind and solar technology that produce electricity. Though electricity is a very clean form of energy, it should be consumed must be consumed temporally and locally close to its production as it cannot be stored efficiently and its transportation implies vast costs in new infrastructure and huge energy losses proportional to the distance transported.

Therefore, biofuels are able not only to provide a temporarily support, acting as a stabilizing agent in the current volatile situation, but also to offer a long-term solution for a more sustainable future.

2.7 Classification of literature

2.7.1 Introduction

In this section, part of the literature on the subject of biofuels on which this study drew inspiration, and valuable information data and concepts, will be presented. The literature gathered consists of research and papers from many authors on various topics with an emphasis on a broad range of biofuels-related factors. They will therefore be presented in accordance with the areas of interest that each has contributed to the topic of this particular study.

2.7.2 Technical literature

The first part of literature, most of which we have already met in the chapter of introduction, is focused on the technological aspect of biofuels. Papers like [41], [42], [43] and [44] that focused on the definition and classification of biofuels into different generations based on the feedstock and different role based on the fossil counterpart that they can complement or substitute. Also, studies that discussed the advance of the production methods through the years in a single or in different generations and how these advances propelled the biofuels industry into the status where

[41] Demirbas, A. (2007)
[42] Aro, E. (2015)
[43] Kandasamy, S. et. al. (2021)
[44] Naik, S. et. al. (2010)

they are today. Through this lens, they are measuring the industry's progress in certain ways, although the majority of the works in this category don't delve into great detail about the geopolitical implications of these advances. They only contributed to a better understanding of the technological state of the field within the context of this study.

2.7.3 Literature identifying – development drivers

Another part of the literature, more related to the scope of this study, though analyzing a diverse field of perspectives, is identifying the major geopolitical drives that affect the development of biofuels. The development is taken into account as a separate industry as well as the competition between oil and renewable energy sources. These forces can generally be distinguished as those that work in favor of and those that work against the development and expansion of biofuels.

Mateete Bekunda in *"Biofuels in Developing Countries"*[45] identifies the main benefits of biofuels that are also the factors that drive their development as:

1. Climate change mitigation. With biofuels substituting fossil fuels and their related GHG emissions.
2. Improved energy security by reducing dependence on uncertain petroleum imports.
3. Rural development by production a locally generated form of energy. Creation of rural employment and wealth.
4. Reduction of deforestation and land degradation and reach sustainability.

2.7.3.1 Climate change / emissions reduction

As aforementioned in the previous chapter, one of the major factors that have renewed the global interest towards biofuels is the issue of climate change and the imminent climate crisis if there is no reduction of GHGs in the years to come. This is recognized in most of the literature such as [46], [47], [48], [49], [50], [51], [52] and [53]. In this literature we can find [S. Puricelli, et.al. 2020[54]] referring to the *"European transport sector that was responsible for more than 25% of the EU total greenhouse gas (GHG) emissions in 2017"* due to the use of fossil fuels and that biofuels could offer a reduction of 7% to 70% depending on the type, the feedstock and the production practices. Furthermore, in US in 2017 with a production of 1.6 gallons of biodiesel[55] - that is not the major state's biofuel production – and an 63% GHG emissions reduction (from 29.3 lbs./gallon for conventional diesel to a 10.8 lbs./gallon GHG emissions for biodiesel) 14.8 million tons of

[45] Bekunda, M. et. al. (2009)
[46] Aro, E. (2015)
[47] Azadi, P. et. al. (2017)
[48] Ditzel, K. et. al. (2018)
[49] Hazell, P., & Wood, S. (2007)
[50] U.S. DOE, EERE (2020) "Algal Biofuels."
[51] De Oliveira, F. C., & Coelho, S. T. (2017)
[52] Timilsina, G. R., & Shrestha, A. (2010)
[53] Bomb, C. et. al. (2007)
[54] Puricelli, S. et. al. (2021)
[55] Ditzel, K. et. al. (2018)

GHGs was saved. That not to mention the fact that sugarcane derived bioethanol produced in Brazil can achieve an emissions reduction of an astonishing 90%[56, 57].

Finally, the increasing demand is emphasized in literature. It is mentioned that even if an oil shortage is not *"envisaged in the 'near-to-medium term', it is calculated that a third of oil reserves, half of gas reserves and over 80% of current coal reserves should remain unused from 2010 to 2050 in order to … meet the 2ºC global warming obligation set out in the Copenhagen Accord."* [58].

2.7.3.2 Energy security / diversity of resources

The aspect of energy security in renewable energy and the fact that it is more evenly spread as a resource globally is crucial[59]. This can lower the global dependence on the oil producing countries and affect the power balances on the geopolitical map. Biofuels, have a primary role in this change of balances, being part of the renewable transformation[60]. Despite huge advances in other renewable technologies such as solar panels and wind turbines, biofuels are the key player in the transport sector, replacing the oil derived fuels.

"Geopolitically induced investments in biofuels" [61] is a study that further supports this argument with her study on the relation of R&D of biofuels and oil crisis. In fact, in the paper, it is examined whether and how the R&D investments are affected by the oil supplies in the poor sources, import-dependent states. The study is based on a sample of 12 EU countries in the years 1997 and 2014 - with a dependency that varies from 14%-100%, when the dependency of on petroleum products varies from 22% to 67%. A correlation is recognized between such investments in energy innovation and the states conflicts with the country's major oil supplier, with a lag of almost 2 years. It is also marked that, two ways that countries improve their energy security is diversification of resources and suppliers and funding of valuable substitutes. Oil price rise is clearly positively corelated with investments on such alternative resources -substitutes, and EU member states tend to promote renewables as such alternative energy resources.

Another, perspective of how energy security is enhanced with the introduction of biofuels, is discussed in the study *"Energy security role of biofuels in evolving Liquid Fuel Markets"*[62]. Through simulation of the US fuel supply-chain and Monte Carlo analysis of oil supply shocks, it was made clear that though biofuels utilization cannot eliminate these supply shocks they can indeed *"…mitigate the negative impacts of those shocks by dampening price spikes…"* and aid economy stabilization during such uncontrollable crises that may arise from external geopolitical events. As referred in [63], energy security is one of the key factors from the aspect of political economy. It is underlined that *"One of President Obama's stated objectives was to reduce the*

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[56] Bomb, C. et. al. (2007)
[57] Alckmin, G., & Goldemberg, J. (2004)
[58] Philp, J. et. al. (2015)
[59] Vakulchuk, R. et. al. (2020)
[60] Aro, E. (2015)
[61] Brutschin, E., & Fleig, A. (2018)
[62] Uría-Martínez, R. et. al. (2018)
[63] Zilberman, D. et. al. (2014)

balance of trade deficit, and substituting imported oil with domestic biofuel does just that." And indeed, as recorded in [64] and [65] *"US oil import fraction has dropped from 66% in 2005 to 42% in 2015 and part of that reduction is attributable to biofuels"* while OPEC imports were reduced from 45% of the total imports in 2000 to 33% in 2017. Biofuels are recognized as a substantial aid, towards this reduction of such a dependency, with a production of 1.6 billion gallons in the same year.

China also has recognized biofuels as a strategy to improve its energy security as it is a net importing country and the greater energy consumer of the world. *"In 2008, China's crude oil imports reached 178 million tons, accounting for 48.5% of its crude oil supply"* making China depended on foreign oil and very vulnerable to price fluctuations[66].

Though, energy security is not only an issue of advanced economies like US and China. Energy security is recognized as the major motivation of oil importing countries, to diversify their consumption and reduce their reliance[67]. It is also marked that *"in Africa, the consumption increased by 15% between 2002 and 2007 while expenditure tripled."* and that large countries like *"Tanzania and Senegal spend about 40% of their foreign exchange earnings on purchasing oil products"*. Thus, internal biofuels production would offer significant security and economic advantages to these countries.

2.7.3.3 Rural development

Rural development is the third but not less important factor, acknowledged of driving forward the development of biofuels. Another factor that is true for almost all types of economies, both developed and developing. As noted in the comparison of biofuels development in Germany and UK[68], for the German Government bioenergy is not only an important energy source for environmental reasons and energy security, but also as a way to support the agricultural industry and regional development. This is a strong point of view not only for European countries but also for developing ones such as Brazil, India and most Sub-Saharan countries that foresee the opportunity to *"create rural employment … alleviate poverty and offer new development pathways in these regions"*[69]. Some highlights of this aspect offered in the paper include the sugarcane farming in Zambia, that resulted in annual family income of $10,250 USD in a country where estimated per capita GDP is $921 USD, and Brazil that has created thousands of jobs in in Brazil's arid northeast hinterland, an otherwise impoverished region of the country, while several other case studies are referred to India, Tanzania, Mali etc.

Finally, China is another great example to support this point of view as it is a country with huge agricultural areas of land and a great agricultural tradition, that however diminishes making the rural regions of the country impoverished. Meanwhile, due to its enormous energy needs, China

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[64] Uría-Martínez, R. et. al. (2018)
[65] Ditzel, K. et. al. (2018)
[66] Zhong, C. et. al. (2010)
[67] Bekunda, M. et. al. (2009)
[68] Alckmin, G., & Goldemberg, J. (2004)
[69] Bekunda, M. et. al. (2009)

has emerged as the world's largest energy user in recent years. Thus, the *"utilization of marginal land for feedstock production of biofuels may provide extra income and employment opportunities for farmers in impoverished rural regions. From this point of view, biofuels development in China not only benefits energy security and pollution control, but also helps to increase the rural economy and improve rural ecosystems."* [70].

2.7.3.4 Sustainability

China, however, did not stay on these 3 factors but tries to expands them in a more holistic sustainable manner. *"By 'sustainable', it is supported both long-term ecological viability and socio-economic equity..."*[71]. The design of the biofuel programs of China do take into consideration the local production of each region according to the cultivated lands and the choice of more efficient crop cultivation[72]. Moreover, there is a turning towards the second and third generation of biofuels where possible with non-food crops such as tuberous crops, sweet sorghum, cellulosic biomass, and algae being between the emerging new type of natural resources, investing and improving the production technology.

The need of a sustainable production is also realized in EU and this is depicted in the change of the regulations on the renewable energy. In Renewable Energy Directives (RED II, 2018) that are a revision of RED 2001 it is required that there will be a minimum of 10% biofuels participation in the transport sector by 2020 and a 14% by 2030. In fact, in 2030, 7% will be the maximum use of first-generation biofuels while the rest portion should be covered by more advanced ones not based on food crops. There are also other restrictions such as the prohibition *"to produce biofuels from biomass cultivated on high biodiversity land and high carbon stock land…". "Moreover, to be considered sustainable, biofuels must achieve GHG savings in comparison to fossil fuels of at least 50%, 60% and 65%, depending on the start date of the plant operation"*[73,74]. The strategy of developing and ensuring such production standards and practices through legislation, regulations licensing and certifications, may *"create difficulties to achieve the short-term production goals of biofuels…"* but this will create a *"need to increase the research and development into the energy production processes"* and eventually result to a more sustainable future in all aspects, (economic, environmental, feedstock production, and agricultural development) [75].

In the study *"Palm oil-based biofuels and sustainability in southeast Asia…"*[76] it is depicted a great example of how in the same region and having the same feedstock three countries (Indonesia, Malaysia and Thailand) can implement strategies that are either sustainable or not. In the article through the analysis of biofuels development from palm trees in all three countries it is clarified how sustainability is not only based on the feedstock and the final product but also on the environmental and socio-economical results from the whole product lifecycle; cultivation, processing, transportation and final production. So, while in Indonesia and Malaysia there is a

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[70] Zhong, C. et. al. (2010)
[71] Mukherjee, I., & Sovacool, B. K. (2014)
[72] Zhong, C. et. al. (2010)
[73] Puricelli, S. et. al. (2021)
[74] Doc. No. Directive (EU) 2018/2001 at Http://data.europa.eu/eli/dir/2018/2001/oj (2018).
[75] Achinas, S. et. al. (2019)
[76] Mukherjee, I., & Sovacool, B. K. (2014)

great production of biodiesel based on palm-oil, the production and expansion of palm-oil has incentivized and induced deforestation, release of carbon from vegetation and soil, forest fires, soil erosion, water pollution and biodiversity loss. It is also stated that, based on satellite and historical records it is confirmed that *"...palm-oil is one of the four largest causes of deforestation in Indonesia alongside logging, agricultural production, and forest fire"*. Therefore, the production in these two exporting countries, despite its significant volume is not sustainable. On the other hand, Thailand, implemented a more modest cultivation strategy, restricting deforestation and cultivating palm trees in marginal lands in its southern provinces, which is also the location for a majority of the country's oil mills and facilities, while considering alternative second-generation feedstock in order to expand to other areas of the country. They also invested on *"initiatives aimed at improving energy security, enhancing employment opportunities and promoting rural development."*[77]. In this way Thailand government reinforced rural employment, achieving an ownership scheme where over 90% of plantations in the country are owned by small farmers. All the aforementioned factors discern Thailand from the other two neighbor countries, providing a far more sustainable product.

As previously stated and will be demonstrated in the following paragraphs, sustainability is not an innate property of biofuels and their production. Nevertheless, it has the potential to be attained when it is considered when designing the strategies so that the best practices are in place at every stage of their production.

Although reviving the production of biofuels can help address a number of contemporary difficulties faced globally, as outlined in the paragraphs above, their production also raises a number of concerns. There are issues that might come up with every new technology and that should be handled as effectively as feasible to guarantee the aforementioned industry's sustainability.

2.7.3.5 Environmental concerns

Biofuels claim to be almost carbon neutral as the GHGs that they emit when burnt a sequestrated during their cultivation. However, there is not a complete balance, as carbon dioxide and other GHGs are also emitted during the production processes. According to studies of the last decade on the carbon footprint of biofuels, they are not so carbon neutral while some of them can even exceed the GHGs emissions of their fossil counterparts[78]. Conducting Life Cycle Assessment (LCA), the emissions in each biofuels production phase, from the cultivation and even before that are taken into consideration. In short *"LCA is a tool for quantifying the impacts associated with the energy and resources needed to make and deliver a product or service"*[79].

Moreover, most of the cultivation areas and especially of the first-generation biofuels, where prior forest or croplands that when afterwards transferred in forest lands, like in some areas of Brazil and most of the acres of Palm lands in Indonesia that were prior tropical forest. These dramatical changes in the use of the land have direct and indirect consequences. *"Direct emissions result*

[77] Sombilla, M. A. et. al. (2009)
[78] Gonzalez, C. G. (2018)
[79] Curran, M. A. (2006)

when land is cleared and earmarked for biodiesel feedstock cultivation. Indirect land use change (ILUC) occurs when forests or grasslands are cleared for economic activity that is displaced by biodiesel feedstock production elsewhere"[80]. *"In 2015, the uncontrolled burning of Indonesian forests to clear land for pulpwood and palm oil sparked one of the worst environmental disasters of the year. The fires released more greenhouse gases than Germany's annual carbon dioxide emissions"*[81].

Finally, there are also concerns on the cultivation practices of several biofuel feedstocks like soy bean that "causes environmental impacts because of the intensive use of pesticides and herbicides" and due to the potential damages caused to soil, water and air, *"soy biodiesel cannot be considered a fully renewable source, since its production is heavily dependent on the use of non-renewable resources in agriculture, process and transport"*[82].

As stated in several studies [83], [84], [85] and [86] the environmental concerns mentioned above have led many environmental organizations and subsequently governmental policies to have a critical attitude towards biofuels and especially towards first-generation biofuels while holding more positive ones about second-generation[87].

2.7.3.6 Deforestation / biodiversity

The issue of biodiversity is another facet of environmental concerns connected to deforestation and the conversion of land into croplands for biofuels. In the literature it is recognized as a crucial issue that occurs mainly in developing countries where the most diverse and virgin lands still exist[88, 89]. Lands as peatlands, and tropical forests that have been burnt down to be replaced by monocultural production, had been home for countless forms of wildlife, flora and fauna destroying biodiversity causing imbalance and *"threatening the land and the public health"*[90].

As also referred in the same article, *"In Brazil, the expansion of sugarcane, soy, and animal feed production for biofuels have contributed to the destruction of the Amazon rainforest as well as the biodiverse mixture of savannah and woodland known as the cerrado".*

2.7.3.7 Food vs fuels

The competition created between the fuel (biofuel) and food industries, which poses a threat to food security as a result, is one of the most contentious arguments made against biofuels and a key factor pushing growth across generations. The food industry and, thus, the sustainability issue are

[80] Mukherjee, I., & Sovacool, B. K. (2014)
[81] Lyons, K. (2015, October 28). Indonesia burning: Forest fires predicted to be worst on record. The Guardian.
[82] Cavalett, O., & Ortega, E. (2010)
[83] Ditzel, K. et. al. (2018)
[84] Gonzalez, C. G. (2018)
[85] Bomb, C. et. al. (2007)
[86] Zilberman, D. et. al. (2014)
[87] Delshad, A. B. et. al. (2010)
[88] Zhong, C. et. al. (2010)
[89] Mukherjee, I., & Sovacool, B. K. (2014)
[90] Gonzalez, C. G. (2018)

compromised by the cultivation of feedstock crops, mostly of the first generation but also some of the second.

The reduced food production results in increasing food commodity prices[91] - putting pressure on others within the agricultural value chain, such as livestock producers, as well as on consumers, especially those at greatest risk of food insecurity and hunger[92].

Additionally, the problem is considerably more pronounced in underdeveloped areas and poorer nations where food security was already in jeopardy prior to the production of feedstock for biofuels. A billion people worldwide suffer from hunger or malnutrition, with more than half of them residing in rural parts of South Asia and Sub-Saharan Africa (SSA) and depending on agriculture for both nutrition and employment. In South Asia there is sufficient per capita food production to feed the population but unequal distribution of food, resulting in pockets of hungry people; whereas in Sub Saharan Africa there is insufficient per capita food production to feed the population as a whole.[93, 94, 95].

A more elaborate analysis on the subject can be found in a study on how *"biofuel production and policies of the United States and the European Union have produced environmental injustice in Asia, Africa, and Latin America by increasing food prices and stimulating large-scale land transactions that deprive local communities of the land and water necessary to grow food"*[96]. It also refers to the rights of the locals on equitable access to food, water, land, and energy that they are denied in many ways, due to large scale production of biofuels required for the northern countries' economies. Finally, ways to set this injustice under the states' control through legislation are discussed in order to protect the more vulnerable citizens[97, 98].

2.7.3.8 Against other renewables & tensions

Last but not least, there are some more concerns identified in the literature, two of which are mentioned below.

The first is about the competition between the forms of renewables and how the investment in one form and the tie of the development on this technology, may hinder the progress of other forms that could prove more efficient and more sustainable in the long term[99]. Biofuels are among many sources of alternative energy, and these other sources, such as solar and wind, are also competing for government support. There is an implicit competition between solar and wind power, which may be used to fuel electric vehicles, and biofuels. Even new providers of natural gas through fracking and other means may see investment in biofuels as a competitor, despite natural gas being a nonrenewable, albeit cleaner fuel, than oil.

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[91] Zilberman, D. et. al. (2014)
[92] Albers, S. C. et. al. (2016)
[93] Bekunda, M. et. al. (2009)
[94] Sachs, J. (2005)
[95] Hazell, P., & Wood, S. (2007)
[96] Gonzalez, C. G. (2018)
[97] Gonzalez, C. G. (2018)
[98] Harnesk, D. (2019)
[99] Zilberman, D. et. al. (2014)

This could apply when examining the competition between biofuels with other forms of renewables, such as solar, wind and geothermal, as stated in the study, but it is also met when examining the biofuel industry itself, realizing the competition between the different generations. Countries and companies that have made investments to develop facilities and technology and promote the production of the first generation of biofuels may not easily take the step invest more to steer the production towards a more environmentally friendly and sustainable second and then third generation. In the same article it is underlined that *"... the existence of a blend wall, second-generation biofuels may find first-generation biofuels to be competitors in supplying a given market."*

The second noteworthy concern was that, while one group of the literature examined supported that the more uniform spread of the resources needed in biofuels production may lead to reduced tensions compared to the fossil fuels market, another group of experts suggested that the renewable energy industry – and biofuels as part of it, comes to compete with the previous status of the oil based one[100]. Thus, extra tensions may arise in the global map as the existing power balance is being disturbed and until a new balance is settled in the geopolitical map.

2.7.4 Studies measuring the development

Except of analyzing and delineating the driving factors of development in the literature there are found some remarkable efforts of delineating also the development. The rates of development are attempted to be measured or estimated, either directly or indirectly and there are even some projections or guesses for the future progress of the industry.

Papers like [101], [102] and [103] use several indexes to estimate the development of biofuels and the evolution of their technology in the world. Paper publications, patents and R&D expenditures in each region are studied, while also statistical analysis on the countries production is held in many of them.

In particular [P. Azadi [104]] was focused on the major changes that the biofuel science has undergone over the past few decades, concerning its focus and its development rates in the different states. 49.000 papers on biofuels published between 1990 and 2014 were analyzed, to identify how different regions evolved through the years what were the R&D outcomes and the corresponding investments. The index used by [E. Brutschin and A. Fleig [105]] in studying the policy direction towards or away of biofuels was the R&D expenditures of each state under examination, and how this varied through the years according to the conflicts of the main oil supplier of the state. Finally, [S. C. Albers et.al. |2016 | [106]] in his study the used the submitted patents as his main indicator of biofuels R&D outcome and development. The patent landscape used, *"encompasses 21,768*

[100] Vakulchuk, R. et. al. (2020)
[101] Azadi, P. et. al. (2017)
[102] Brutschin, E., & Fleig, A. (2018)
[103] Albers, S. C. et. al. (2016)
[104] Azadi, P. et. al. (2017)
[105] Brutschin, E., & Fleig, A. (2018)
[106] Albers, S. C. et. al. (2016)

inventions…, represented by 66,170 patent documents published by 81 patent offices, … by residents of 100 different countries”. Although patents and invention outcomes was the main indicator of this study, this also took into consideration the actual production and related these two indicators with the oil price and other geopolitical events that occurred during the studied period 1970-2013, such as the 9/11 terrorist attack in 2001, the financial economic crisis, the new oil resources that became available through fracturing and policies implementation like Renewable Fuel Standard (RFS) introduced in the United States in 2005 and strengthened in 2007 and Europe’s Emissions Trading System (ETS) launched in 2005, that encouraged development of technologies to replace fossil fuels.

These kind of studies does not always introduce a geopolitical perspective in their analysis, however, the regional classification that is part of these articles could prove revealing of the geopolitical development, the strategy to be adopted by each country or region, and it can give great insight to the geopolitical reality when such a filter is applied. It also is very helpful in spotting the leading countries in the biofuels field, the states that take the research further and the ones that lag behind. Such kinds of classification can be affirmative of the decisions of each government’s policies and measure the results of it when related to specific geopolitical events. A relation between oil supplier’s conflicts – disturbance on supply and the investments performed in the field of biofuels, is presented in literature[107]. The study notes that countries who’s the major supplier was the more unstable Russia during the study’s period were investing more than the ones that had Norway or Middle east as their major supplier.

Of the other two studies it can be extracted that the leaders in biofuels research lately are EU with a 28% of the publications followed by China and US with 16% and 15% respectively publishing the 60% of the global papers, while *“…other significant contributors were Japan, India, Brazil, Canada, and South Korea”*. R&D output is closely corelated with the R&D investment (r=0.98!), while it is confirmed the correlation of the oil price and the expenditures on biofuel research as an alternative[108]. Some highlights of the same study are that the countries with the higher biofuel production per capita are Identified to be: US, Brazil, Argentina, and Belgium, while bioethanol constitutes above 80% of the liquid biofuels in United States, Brazil, Canada, Australia, and China, while biodiesel accounts for more than 60% in European countries (except for Britain). Finally, according to feedstock, bioethanol in US and China is primarily produced from corn, in Brazil from sugarcane and from wheat and sugar beet in EU. On the other hand, biodiesel is obtained from esterification of vegetable oils of rapeseed in EU, soybean in US, Argentina, and Brazil while palm oil is the major feedstock for Indonesia and Malaysia.

[109] adds in the study the time variable when examining the evolution of the patent’s applications. In this way, even if the same key players are recognized, Japan is identified as an early leader between 1994-2002 while EU an US followed in 2004 and 2005 respectively. China and Korea had a later start in 2000, peaking also in 2004. The Global peaking was found to be in 2009 and then the patent filling diminished. The decline was different in different regions with US keeping

[107] Brutschin, E., & Fleig, A. (2018)
[108] Azadi, P. et. al. (2017)
[109] Albers, S. C. et. al. (2016)

a steady rate while EU rate fell by 1/3 and the rest of the western world almost by 1/2. Nevertheless, in China and South Korea the growth continued in high rates with China doubling its patents' fillings from 2008 to 2013, surpassing US who held the first position and keeping the global rate of inventions to the positive while the rest of the world is falling with a 4% rate. In general, the development of biofuels innovation had a slow beginning, followed by a significant increase after the 70s oil crises and a second even higher one during 1995-2005. Then for a short period of 3 years the patents applications quadrupled reaching a growth of 68% in 2006 but then after the economic crisis it fell again reaching to 3.9% in 2013, leaving China as the only really fast developing country in the field.

2.7.5 Comparative – case studies

The last sector of the literature on biofuels that is of great importance for the scope of this study, is the journals and papers that examine local and regional cases. Articles such as [110], [111], [112], [113], [114] and [115] focus on one country, mainly out of the key players in the sector, like Brazil, US, China and EU countries, though there are also interesting cases in countries, regions, or a group of similar countries (from the biofuel perspective), that either are currently developing their biofuel sector of have contradictory incentives on developing biofuels products. Studies that examine the status for biofuels in Southeast Asia with – Indonesia, Malaysia and Thailand, and developing countries with case studies on India, Mali, South Africa, Sub-Saharan Africa, Zambia etc. respectively[116], [117].

Finally, there are also comparative studies between these countries and regions, in order to underline specific aspects of the development where they share similarities or exhibit differences. Such studies are [118] and [119] that discuss the similarities and differences that can be met inside the same continent or a wider region respectively. In particular the former compares biofuels development implementation in Germany and UK, while the latter presents the similarities, differences and synergies in the development path of US and Brazil's biofuels' industry.

As these articles will also serve as source for the rest of the study, a more elaborate description on the issues they discuss and detail on their findings will be met in the fourth chapter.

[110] Ditzel, K. et. al. (2018)
[111] De Oliveira, F. C., & Coelho, S. T. (2017)
[112] Puricelli, S. et. al. (2021)
[113] Zhong, C. et. al. (2010)
[114] Achinas, S. et. al. (2019)
[115] Agarwal, S., & Kumar, A. (2018)
[116] Bekunda, M. et. al. (2009)
[117] Mukherjee, I., & Sovacool, B. K. (2014)
[118] Curran, M. A. (2006)
[119] Sajid, Z. et. al. (2021)

Chapter 3: Methodology

3.1 Scope of the thesis

Several technical studies on biofuels technology, feedstock, and processing were found after reviewing literature. Additionally, a sizable number of papers have been written about the technological, geopolitical, and more particular factors affecting the growth of the biofuel sector. These factors all have an impact on the development of the renewable energy movements in general. In such studies several countries development is presented as case studies to support the analysis involved. The focus of another section of the literature is on the development occurring in a specific area, region, or country, describing the historical occurrences and the factors that contributed to this form of development. Some of these studies also make comparisons between regions exhibiting comparable or dissimilar forms of development in order to provide a deeper understanding of the cases being discussed. Finally, studies that compare the progress of each producer using a variety of indicators are available. These studies aim to provide an overview of what is happening internationally in the biofuels industry. However, the latter leave out the geopolitical factors that contributed to the resolved conflicts.

This study aspires to provide an overview of the major participants in the biofuel sector, similar to what the latter do, however, taking into consideration the geopolitical perspective. We will attempt to present the historical development of the major producers, paying more attention to the last two decades, and look at the factors that led to the various courses from a geopolitical perspective utilizing the literature and data on global production as well as the production of each region and state.

3.2 Course of analysis and data sources

In particular, having identified several drivers that are important for the development of biofuels in the literature, there will be an attempt to align the course of each producing state to these specific drivers. A global production overview and a division of the major regions involved in the biofuels industry are presented as the first stage and first component of our methodology. Following that, the principal producing nations in each of the important locations will be determined. The resource that is used for both these attempts to detect the main actors, is the BP – Statistical review of worlds energy (2021).

In the next section, each of the identified states will be analyzed separately. Production data and state choices on the production will be presented, while also the factors that led to these productions will be explored. The former part, come mainly from the United States Department of Agriculture – Former Agricultural Service reports of the countries involved. The decision to use these reports, was made as they offer plenty and concentrated data, but mainly because, as there are similar reports for every point of interest, we could have a common base as a reference so that the presented data could be comparable. For the latter part, studies on specific regions and countries fount in the literature proved to be very useful, providing valuable qualitative information and insight to the reasons and the drives of each industry that come to complement the aforementioned data.

Concluding, there will be a summary of these case studies, and the alignment of each state with the earlier identified factors, and some comparisons between the states in each factor, aspiring to offer the larger picture from this perspective.

Chapter 4: Analysis and results:

4.1 Introduction

As it was made clear, biofuels have seen a great rise in the past decades as they are perceived as a possible solution to the deteriorating issue of climate change, and a great aid to the energy security of each state, especially for the ones with scarce or no fossil resources.

The rise described is depicted in Figure 2. There, as it is presented, after an almost steady decade for biofuel production between 1990 and 2000 dominated mainly by South followed by North America, incentives appeared in 2000 and a rise began from 2000 to 2005, in three continents; North America, South America and Europe. Then after 2005 when policies like the US Renewable Fuel Standard (RFS) and the European Emissions Trading System (ETS) were established and further encouraged the growth, this rise became steeper while close to 2010 the biofuels' industry was introduced in the region of Asia Pacific.

Despite of a slight drop observed globally in the years of economic crisis (2012) and a sharper one during the Covid-19 pandemic (2020), the last decade (2010-2020) was also characterized from a general growth. In the years after 2017, a stagnation is also observed for the early and major producers; North and South America, while a slight and a higher growth was met for Europe and Asia respectively. Finally, it should be noted, the lag of the regions of Middle East, CIS, and Africa, which for their own reasons each have still a scarce production and an even scarcer growth.

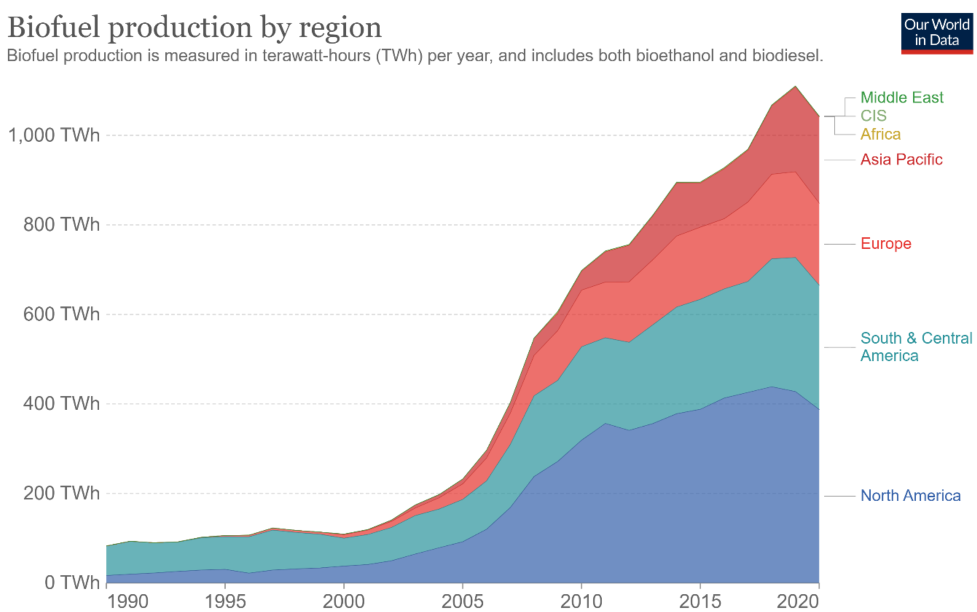

Figure 2 Biofuel production per region (Tw/year)[120]

Moreover, despite the relatively low global production of biofuels compared to the established oil market, a new fuel energy market is created around them that expands; transforming from local to

[120] BP Statistical Review of World Energy (2021), 70.th edition.

regional and then global, and affects the geopolitical map. However, as mentioned in the literature review there are several different factors that affect the evolution and the development of the biofuels either in favor or against this expansion, and each factor affects each country in a different way, based on its current state and its progress through the years.

The leadership of US and Brazil as the earliest and greatest producers is clear, as in 2020 having suffered losses of 9% and 4% respectively – as presented in, they produced almost 60% of the global biofuels with about 36% for US and 24% for Brazil, while the whole regions of Asia and Europe produced 18,5% and 17,5% respectively.

Based on the data presented above, and on the literature review, the active regions in biofuel production can be easily spotted as well as the key players in each region. As mentioned North and South America are the regions with the largest production with Asia and Europe following close by, while the key players of each region can be also identified. North America has US as its one and major player with 97% in 2020 similarly to South and Central America where Brazil is the leader with 89% of the production when Argentina the second producer in the region produces a mere 7,1%. In Asia (Asia Pacific) along with the Europe production is more evenly spread, however some key players can be identified there too. For Asia these countries are Indonesia (28,4%), China (26,8%) and Thailand (16,7%). And in Europe, there is a lead from Germany (26,5%) and France (19,5%) followed by Netherlands (9,2%) and Spain (9,1%), while there are several other countries with a production of over 2,5%.

Having identified the key players and based on these statistics in the following section a presentation of each of these countries biofuels industry will be presented. In some regions other states may be also worth mentioned.

4.2 North America

As shown in Figure 2 north America is one of the two early producers in the biofuels industry and the largest globally since 2006. Consisting of three countries, its main producer is US with the majority of the production while Canada although supporting biofuels has not achieved a significant production while Mexico despite its ideal climate due to its positioning close to the equator is still in the infant stages of production.

4.2.1 US

The United States of America is not only the main producer of North America, but the greatest producer in the world with an annual production of ethanol that reached an all times high of 16 billion gallons or 73 billion liters in 2018, and a respective biodiesel production of 2.5 billion gallons (11 billion liters) in the same year[121]. It is also stated that *"In 2018, the American ethanol industry employed 71,367 people, created 294,516 jobs, contributed $25 billion in domestic*

[121] Renewable Fuels Association: Annual ethanol production

income, and increased the gross domestic product (GDP) by $46 billion"[122]. As made clear its main biofuel product is Bioethanol, whose main feedstock is the existing and expanding corn crops of US. Corn crops exceeded 90 million acres in 2019 according to USDA[123], while in 2020 40% of this land was dedicated to ethanol production. Corn that is responsible for the 90% of the production is a first-generation biofuel feedstock, and despite the advanced cultivation techniques and fertilizers used in the US crops, it can achieve a fuel yield of only 400 gallons per acre, compared to more advanced biofuels like cellulosic which is estimated that can reach 1000 gallons per acre. Even though the production could get even higher and more efficient, the bleeding edge refinery facilities that utilize economies of scale in US significantly reduce the cost of production, that makes US have one of the most price effective bio-ethanol globally.

Following the historical evolution of biofuels production in US, it is evident that the oil crisis in 1970 was the revival event for US too. Nonetheless, the rise noted after 2005 that was the turning point for US making them the largest producer, surpassing Brazil that was the leader until then. This production boost was made after biofuels were introduced in the strategical plan of US. And that plan was materialized and supported through several policies. The Energy Policy Act, and the Renewable Fuel Standard (RFS), were both came in place in 2005 by the Environmental Protection Agency (EPA), that was founded to protect the environment and human health. RFS has two ways of affecting biofuel production: On the first hand, it mandates the utilization of biofuels in the fuels market, requiring a participation share, and in the way ensuring a demand rise and a safe market for the producers, and on the other hand, regulating the production, requiring standards such as establishing guidelines and benchmarks for ethanol. In particular, according to first-generation biofuels, such as ethanol produced from corn, should produce 20% lower GHG from gasoline; advanced biofuels should decrease the emissions of greenhouse gases by 50%, while the use of cellulosic based biofuel should reduce greenhouse gases by 60%[124].

In 2007 RFS was revised, upgrading the role of sustainability in its mandates. An example is the statement that *"renewable biofuels could not be obtained from the land converted to agriculture production…"* and that *"by 2022, the 36 billion gallons of biofuels should be dedicated to ethanol production, of which 16 billion gallons must be cellulose-based"* that is more efficient regarding the production per acre. In the same year the Energy Independence and Security Act (EISA) was established that was named afterwards Clean Energy Act that set the targets of 9 and 36 billion gallons of biofuels by 2008 and 2022 respectively. Such policies, complemented by several other more specific laws, subsidies and tax reductions gave to the US production the boost to rise faster than the completing Brazil and take the lead in 2016.

There are still concerns about the economic viability of biofuels expressed in articles such as *"Green peace: Can biofuels accelerate energy security"*[125] where the issues of price efficiency compared to oil products and resource requirements concerns about its production are placed, making them counterproductive to national energy security. It is also discussed the fact that the

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[122] Sajid, Z. et. al. (2021)
[123] USDA ERS—Feedgrains Sector at a Glance
[124] Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program (2010)
[125] Gay, J. E. (2013)

demand of U.S. and EU to meet their goals will eventually rise the price of crops and lead to food deprivation poorer countries where their lands have more potential for this production. The latter is highlighted by an estimation that *"global food prices could rise by as much as 76 percent by 2020, pushing another 600 million into hunger if U.S. and EU biofuels goals are met and no other action is taken to prevent hunger."*

Concerning the factors affecting the biofuel industry, from all the above it can be extracted that, despite the oil reserves made available by fracking in 2008, biofuels have become a part of the US strategy. They are a way to enhance their energy security, and simultaneously to address the climate change and fulfil their commitments to the Kyoto Protocol and the Paris Agreement. As a fruitful byproduct, biofuels' production was a leverage to substantially support the rural development, giving a boost to the existing corn production. Sustainability is a factor that was lately introduced in US concerns as corn may be more economically meaningful but is not the ideal feedstock to address the climate change and the food vs fuels conflict, though the latter does not directly affect the largest part of US population but rather that of other poorer countries. Oil and the price of its products are still affecting the growth of biofuel production, nevertheless, their industry has acquired the critical size and stability required to evolve some independence and have a steady expansion in the year to come.

4.3 South America

As North America have Us as a champion in the industry, South America has Brazil. Thanks to Brazil, South America has developed a tradition in the biofuel industry that also began as a result of the oil crisis of 70s that incentivized an extensive program and encouraged the institutional development for bioethanol production through specific policies. Argentina is the second producer of the region holding a small but significant share of 7.1% of the biofuel production, diversifying from Brazil as its main product is soybean biodiesel and not sugarcane bioethanol.

4.3.1 Brazil

As mentioned above, Brazil is the second greatest biofuel producer globally and the previous leader from 1970s to 2005 when US its tremendous growth rate of 2000-2015 surpassed them. Its biofuel production amounted to 15.3 billion gallons (63.2 billion liters) in 2020 that was close to one quarter of the global production. From this fuel, almost 90% was bioethanol 13,9 billion gallons and a mere 10% 1,4 billion gallons was biodiesel. *"Brazilian soil has important mineral contents and a tropical climate that favors the growth of crops"*[126]. The main feedstock in Brazil is sugarcane for the production of bioethanol - 95% followed by corn with 4% - and soybeans for that of biodiesel[127]. Sugarcane is the second main reason of Brazil's great progress in the biofuel sector, after the advantage of the tropical location with such vast tracts of arable land, as it has

[126] Sajid, Z. (2021)
[127] USDA - Brazil: Biofuels Annual 2019

almost the double efficiency of fuel production compared to the corn crops, about 800 gallons per acre.

The tradition of sugarcane cultivation in Brazil comes from a long time ago, in 1500 when it was colonized by the Portuguese[128]. In the colonization period the sugarcane cultivation thrived and expanded, and only in the 1800s it lost its competitive advantage and declined, but in the beginning of the next century the production was modernized and began to grow again[129]. So, during the oil crisis of 70s when the price of oil products skyrocketed with an increase of 40% per year, while the sugar prices decreased due to reduction of the demand in the international market, biofuel production from sugarcane became an economically meaningful solution[130]. Incentives were given through public policies such as the 2 national programs, PROÁLCOOL in 1975 (National Alcohol Program) and PROÓLEO in 1980 (National Biodiesel Program). Nonetheless, they had different fates, as PROÁLCOOL, the ethanol program, advanced and made Brazilian bioethanol industry one of the leading biofuels industries up today, while PROÓLEO, the biodiesel one, came to an end very soon after its establishment[131]. The main reason of turbulence in both programs was the discovery of Brazilian oil reserves that reduced the oil price again and took the competition high[132,133]. This was a shock that PROÓLEO as a younger program, less established and less economically viable could not compete with, whereas PROÁLCOOL, as most established and with more and less expensive feedstock available, managed to overcome and thrive. This program in synergy with the National Alcohol Commission (CAN), achieved a production of 12 billion liters of bioethanol in 1986 when 96% of cars sold in the same year, to be moving on ethanol. Despite a fall in 90s due to the fall of the oil price, the bioethanol industry survived on the demand created by the wide spread flex engine that could be powered by ethanol gasoline or any blend of these two fuels. In this was Brazil was the undisputed leader entering the 2000s in the absence of other important competitors, producing even over 70% of the global biofuel production.

So, when issues of climate change and national energy security aroused, and the global interest was directed again on biofuels, Brazil had the lead with an already well-established industry. Mandates of E25 in 2003 and E27 in 2015 and flex-fueled vehicles[134], create a new demand (biofuels accounted for 48% of light transport fuels in Brazil in 2013), thus boost the production even further, empowering an industry that offers more than one million jobs[135], supporting the Brazilian agricultural sector, even if there are some social imbalances in the distribution of the production across the country. A more balanced spread of the production is achieved in the feedstock of biodiesel that is also rising in the last decade 2010-2020. This happens as while soybean is the major one, other tropical plants are also use in the production such as canola, castor bean, palm, peanut and coconut, that flourish in different regions of the country each. Lately, even

[128] Sajid, Z. (2021)
[129] Nastari, P. M. (1983)
[130] Ackrill, R., & Kay, A. (2014)
[131] De Oliveira, F. C., & Coelho, S. T. (2017)
[132] Zilberman, D. et. al. (2014)
[133] Youngs, H., & Somerville, C. (2012)
[134] Stattman, S. L. (2019)
[135] Bradley, R. et. al. (2005)

used oils and sewage sludge is used as feedstock, at a share of 25%, taking the production towards the second generation and dampening the conflict of food vs fuel.

Finally, it is worth mentioning that Brazil is the world's biggest exporter of fuel ethanol, creating several international agreements to empower biofuel technology and its exports. One of the first was the Memorandum of Understanding (MOU) signed with US in 2007 to support the collaboration on research actions between the two countries, and the tariff free trade quota between US and Brazil that was signed in 2014. Moreover, Brazil has established cooperation with European countries, such as the Netherlands, with whom is signed an agreement of advancing towards establishing sustainable biofuels crops, investing in sustainability. Simultaneously, international agreements with EU are also signed such as the EU-MERCOSUR Free Trade Agreement (FTA) that was signed in 2019 after almost 20 years of negotiations, and promotes the biofuels exports towards EU, which is one of the largest markets for biofuel, while certifying that several production standards have been met and promote the sustainability, supporting the development of small- and medium-sized enterprises. In this way Brazil is developing synergies with other countries in its region and expanding its market strengthening its position in the industry.

Summing up, from the perspective of the factors that influence biofuels' development, it is clear that Brazil had a quite different trajectory compared to US. Energy security was the most significant factor for the development of biofuels through the years, and the oil price was a crucial factor especially in the early stages of development. Then, as a developing country, the support of its rural-agricultural economy and the creation of agricultural job positions was the second most significant factor, while climate change and sustainability seem to affect indirectly the development of the industry in Brazil, mainly through quotas, international agreements and market regulations. Brazil has also made environmental commitments, signing the Kyoto Protocol and the Paris Agreement (2015), where they set targets of 37% and 43% GHGs reduction compared to 2005 in the years 2025 and 2030 respectively advancing its environmental agenda in the last decade even if this was not the motivation for its first biofuels development. Furthermore, sugarcane, although more efficient than corn crops, is also a first-generation feedstock that is competing with food and several concerns have arisen on this issue however the economic growth achieved in the country, seem to be more helpful than harmful. Lastly, as far as deforestations and biodiversity is concerned, even though Brazil faces a great amount of deforestation of the Amazon rainforest that is habitation to various forms of fauna, biofuel crops, are not one of the major reasons for these deforestations.

4.4 Europe

Europe, in comparison to the two aforementioned continents, has a completely different profile in its biofuel development. No state-champions can be found in the region even if some countries like Germany (26,5%) and France (16,5%) are more advanced than others while Netherlands and Spain are close behind with 9% with Spain being also the leader of Ethanol production. Moreover, there is a focus to the production and consumption of biodiesel, however, there is no strong preference as its share in the market is about 70% compared to the over 90% of bioethanol met in the previous case studies. Nonetheless, in absence of a strong competition in the rest of the regions which are focused more on bioethanol production, EU is considered the leader in biodiesel production globally with a production of 3,4 billion gallons (15,53 billion liters) in 2020 when its bioethanol production reached only to 1,2 billion gallons (5,47 billion liters) in the same year[136]. EU reached its maximum production in the year 2019 before the Covid-19 Pandemic reaching 5,43 billion gallons production (24,68 billion liters) reaching 17,3% of the global production, surpassing the 17,1% Asia's production. As EU member states have quite different approaches in production, and agricultural and economic development, there is neither clear preference regarding the feedstock. For biodiesel production, Rapeseed oil have the largest share in the market with 41% followed by Used Cooking Oil – that is a second-generation biofuel feedstock – with 21% and Palm oil with 18% that is not actually produced in EU but imported as raw material. Respectively, for bioethanol production sugar beets with a share of 40% and corn with 35% are the most used feedstocks that with a 14% of wheat amount for 90% of the total feedstock.

Despite its significant biofuel production, Europe's consumption is somewhat larger. And its vast energy consumption combined with the biofuel caps inserted to meet the climate targets set in the Paris agreement commitments, further increase the requirements for more biofuel. Particularly, in 2019 the consumption demand surpassed the production for almost 4,6 billion liters, over 20% of its internal production. This is why, as aforementioned, EU as a great importer, is considered to be one of the largest biofuels markets for the producer – exporter countries in the rest of the world. And being from the side of the importer, gives EU the opportunity to set and raise the standards of the market and give the directions to a more sustainable production. Examining the European leadership in the sector of environmental regulations, on the one hand there is a movement towards more efficient and sustainable feedstock and methods of cultivation, taking into account the direct and indirect land usage and the Life Cycle Assessment (LCA), so that the produced biofuels to become certified and acceptable in the European market, while on the other hand it is noted that at least in the early regulatory stage, EU regulations and legislations on biofuels imports were applied mostly on the basis of protectionism of its internal producers, excluding more efficient biofuels that came from abroad in order to support the factor of energy security[137].

These policies are expressed through the directives RED (Renewable Energy Directive) that came in place in 2009 and RED II that was established in 2018, to upgrade correct and regulate previous deficiencies of RED, while also in the commitments made in the European Green Deal. Specifically, RED that was in effect in the decade 2010-2020 was the first directive that addressed the use of biofuels in EU as a central policy, aspiring to align the specific laws of each individual member state. In this first attempt, the goals set were more generic, and mostly targeted towards mandating the introduction of specific shares of renewables and biofuels in the energy mixture the states, (10% of renewables in the energy used for the transport sector be 2020)[138] – Creating in this way a surge in the demand of production and imports. As stated, however, in several critiques on EU's leading role in regulations towards sustainability, the criteria set in RED regarding the origin and the processes used in the production of these biofuels were now strictly set, allowing each

[136] USDA - European Union: Biofuels Annual 2019
[137] Afionis, S., & Stringer, L. C. (2012)
[138] USDA - European Union: Biofuels Annual 2019

country to apply their particular rules, that many times operated as a protectionism umbrella, promoting the internal production over imports.

RED II, that was signed in 2018 and adopted by EU member states two years later and for the next decade (2021-2030), came to correct those deficiencies, taking into consideration environmental and sustainability criteria such as the indirect land usage conversion (ILUC). RED II did not only raise the goals for 2030 to 32% of renewable energy by 2030 from 20% in 2020, and 14% in the transport sector from 10% in 2020, but also set quality criteria on the biofuels that would cover these needs. Particularly, there is a maximum of 7% of first-generation biofuels in this 14% of biofuels in the transport sector, requiring the rest 7% to be covered by second-generation biofuels and advanced biofuels that would have a double count in the mixture, while this will be certified either by the European EC scheme or through other voluntary schemes approved by the EC. Acceptable feedstock would be algae, biomass from municipal, household, forestry or industrial waste, animal manure, straw and other non-food cellulosic material, while also used cooking oil and some categories of animal fats. This however will affect a lot the imports made from Brazil and US that were based on corn and Asia, especially the imports from Malaysia and Indonesia that are based on palm oil, as the allowed feedstock would be palm oil mill effluent and empty palm fruit bunches, cobs cleaned of kernels of corn, dramatically changing their production requirements, or otherwise reduce the imported quantities from these regions. The latter will make it difficult for both sides as some of these regions support their economies through the biofuel trading, while EU member states that also utilized feedstock cultivation to support their rural development will have to reform their production while simultaneously are requested to achieve even higher goals, proposed in the Green Deal – 55% GHGs reduction of the 1990 levels by 2030, compared to a 40% reduction, previously agreed.

It should be noted that EU, from the perspective of energy security, utilizing biofuels manages to cover a portion of its energy demand with its own production while also importing from several developing countries around the world, applying a double diversification approach to reduce dependency from its main oil suppliers, Russia and Middle east. A diversification of resources, adding a new energy product to cover the rising demands, while simultaneously a diversification of its suppliers as the imports made on biofuels come from other regions, such as Latin America, Africa and southeast Asia. In this way EU is dividing the risk trying to disassociate from its traditional energy providers that create a dependence relation.

Examining the factors that drive EU biofuel industry two major components can be identified. First and foremost, the major issue of a resource poor but with great energy needs developed region is its energy security. An issue that EU is always striving to solve or at least mitigate the consequences in periods of crisis. Secondly, it comes the commitment to an environmentally friendlier, and more sustainable future, and EU's role as a leader towards this direction. A leading role that may arose from the former factor, as EU had not many alternatives, nonetheless it is supported through the years. Moreover, its rural development may be a byproduct of the two aforementioned factors, but it is a lucrative and welcomed one. As conflicts are concerned between biofuels and other renewable technologies or the oil industry in EU, there does not seem to appear such an issue as the poor oil resources of the region leave space for development to all competing technologies. Nevertheless, oil prices and relations with the suppliers still affect the rate of development of these technologies[139]. Finally, although EU as a more developed region does not face direct impacts concerning food vs fuel competition but mostly indirectly inflicts this damage to other poorer regions, based on sustainability criteria, in the last decade it takes into consideration such issues, as well as biofuels production efficiency and deforestation. The latter may hinder the boost of the production in the first place, it enables however a more stable and sustainable development in the long term.

4.5 Asia

Another significant biofuel producing region is Asia and more specifically Asia-Pacific as the area of the Middle East with the vast oil reserves seems not interested yet to participate in biofuel production. It may be the latest starting producing region out of the significant producers, with a production that only surpassed the 5% of the global production in 2006, nevertheless it grew rapidly to reach a significant 18.5% in 2020 with an average growth rate of over 9% since then, while it is the region that holds the lead in the research and innovation in the field when other regions reduced their R&D production[140]. The most significant producers in the region are Indonesia and China, with a share of 28.4% and 26.8% respectively followed by Thailand with a 16.7%. India is also worth mentioned though its 7% of the total production of the region, as it is a controversial case, with a great population and a huge area of land, with great potentials, nonetheless also with great barriers to overcome.

In general, the Southeastern part of the continent, due to its climate that is warm and humid, as it is close to the equator, and its fertile land can achieve great agricultural production, thus have a potential also for biofuel development. However, each of these countries have a different way to approach this development as their motives vary even if they are located in the same region. Their population, their area, their geographical landscape and their economic state prioritize different factors for each one of them. Correspondingly disparate is the production of each state. China and India are investing on bioethanol production with Chila reaching almost 86% of its total production based on corn and rice crops, and India having a share of 93% respectively based on molasses. On the contrary, Indonesia is producing mainly biodiesel based on palm oil (98%), while Thailand is following a more balanced production with about 55% biodiesel and 45% bioethanol.

4.5.1 China

China is nowadays the world's industrial producer, and one of the largest and fastest advancing economies in the world, competing with US for the leading position. Indeed, this pace of development and the vast industrial production requests for similarly vast amounts of energy. Energy, that China until today, is trying to cover through imports and the use of coal, that is its main energy resource. Therefore, energy security is one of the main factors driving China's interest towards biofuels, as it happens from earlier years with other more popular forms of renewables

[139] Brutschin, E., & Fleig, A. (2018)
[140] Albers, S. C. et. al. (2016)

such as wind and solar energy. *"China's crude oil imports have been increasing since it became a net crude oil importing country in 1996"* while they *"...reached 178 million tons, accounting for 48.5% of its crude oil supply"* risking China's energy security[141].

In the same paper, it is highlighted that in the energy mixture of China in 2007 *"fossil fuels accounted for 92.7% of its total energy consumption in which 69.5% came from coal, 19.7% from oil, and 3.5% from natural gas, while nuclear and renewable energy only accounted for 7.3%."* pointing out that there was a lot of room for development, and that Kyoto Protocol's commitments and even more the environmental reality of China's urban area (with degraded water and air quality due to pollution) are factors that exert pressure in this direction. Moreover, the environmental commitments of China were renewed in 2020 at the Climate Ambition Summit where a target of peak carbon dioxide emissions by 2030 and a share of 25% for non-fossil fuels in China's energy consumption by the same year were set[142].

Finally, the sector's development is also a way to further reinforce the rural economy of China. As food production is always a driving force of the agricultural employment of China, biofuels are not a game changer in this sector, as they are in other countries like Brazil. Nonetheless, the 200.000 jobs that were created until 2010 from the biomass industry in the country are an important boost in the development of the rural areas that are based on food or non-food crops. It is worth noted that these positions account for almost 20% of the employment in the renewable sector (1.1 million workers) and that biofuels have a significant share of the sector[143].

In literature it is mentioned that its production is steering towards second-generation and more advanced biofuels such as algae ones, while subsidies on wheat and corn derived biofuels have been halted for some years now[144]. It is also noted that China is making this turn towards more efficient non-food crops, as they have suffered from food shortages in the past, that threatened their food security. Although, biofuels were not the main reason of the rising food prices as it was the corn exports, they had their role in this food crisis. As a result, the Ministry of Agriculture created a plan to guide the production towards cultivation, neither competing with food production nor with the land used for food production, such as sweet sorghum, cellulosic biomass, and algae.

Regarding the production metrics though, the strong motives of China to raise the share of biofuels in its energy mixture while at the same time to steer its production towards second and third-generation biofuels, is far from being achieved, despite the fast pace of development that the country have reached. As the reports show, only 2.5% was the highest blend rate achieved in the last decade, and this happened in 2012, as even large amounts of production and imports are not able to compete with the vast and even faster rising energy demands of the state. Additionally, according to feedstock metrics, only biofuel production is based on a second-generation feedstock, namely used cooking oil (UCO)[145]. The biodiesel production, however, was almost 1,5 billion liters in 2020 that is only 11% of China's total biofuel production. As far as bioethanol is concerned

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141 Zhong, C. et. al. (2010)
142 USDA - People's Republic of China: Biofuels Annual 2021
143 Institute for Labor Studies (2010) Study on Green Employment in China.
144 Zhong, C. et. al. (2010)
145 USDA - People's Republic of China: Biofuels Annual 2021

almost 12% of the production was based on Cassava in 2020 while the rest of it was still first-generation biofuels mostly corn and rice. It becomes obvious that though China has tried to steer its production to a more sustainable state, this turn is going to take quite a long time.

4.5.2 Indonesia / Malaysia

While the volumes of biofuel production of Indonesia and Malaysia are different by an order of magnitude, with the former producing over 8.5 billion liters in 2020 while the latter produced 1.2 billion, they will be examined together as their development format and their strategy are quite similar.

First of all, both have focused their production on biodiesel letting bioethanol on the side, with Indonesia producing 98% biodiesel while Malaysia is not producing bioethanol at all[146],[147]. There may be several reasons for this choice, but they can be summed up to economic viability, as there is a *"lack of economies of scale and high costs make ethanol production using cane or molasses untenable"*[148], while this does not apply for palm oil that is the main feedstock (over 95%) of their production is traditionally cultivated in the wider region since 1300. In literature it is stated that these two countries *"have dominated regional production since the mid-1960s"*[149], producing more than 80% of the total palm oil globally. The biodiesel targets of EU that as mentioned earlier is a large importer and the exporting strategy of these countries played also a significant role.

Both countries have established mandates on biofuel use in their fuel blends. Indonesia indeed had set a target of reaching a blend rate of 30% in their fuels by 2020 from an established 20% in 2019. This is however, postponed due to covid-19 shortfalls. The same in smaller range has happened in Malaysia, whose blend target of 10% (B10) was reached since 2017 however the new mandate to reach 20% is postponed to mid-2022. Despite these mandates that require for a significant use of the production, both countries have based their development on an exporting strategy. As large markets have shown interest in their biodiesel production, Indonesia and Malaysia have become exporters to EU, China and sometimes US, with EU being the most important, accounting for about 70% of their exports.

However, newer regulations that came in force after 2015 and take into consideration the sustainability of the feedstock and the production processes, raise concerns for the production of both countries. Directives such as European RED II and the US RFS, request for sustainability criteria not fulfilled by the Indonesian and Malaysian palm oil production and this will either transform the production directing it to an alternative feedstock that is not affection biodiversity and cause deforestation, or will reduce the exports by a lot as the aforementioned directives will block large amounts of biofuel to be traded in those former markets.

Summing up, the factors of driving Indonesia and Malaysia biofuel industry, seem to be primarily their economic and rural development. having created an exporting strategy to create jobs and

[146] USDA - Indonesia: Biofuels Annual 2021
[147] USDA - Malaysia: Biofuels Annual 2021
[148] Sheil, D. et. al. (2009)
[149] Sheil, D. et. al. (2009)

income for their states expanding palm oil production as fast as possible, and secondarily as collateral benefit, by adding biodiesel in their consumption mixture they achieve energy security and reduce their carbon footprint. This in made clearer when we consider that despite, embodying biodiesel in their national strategy in production, consumption and exports, sustainability is not taken into consideration at all. As referred in the introductory chapter, massive deforestations have happened in the region with fires that had a great carbon output creating a carbon dept while also threatening biodiversity and degrading land and water resources[150]. Sustainability, including food production, deforestation, choice of more advanced feedstock and efficiency of production methods were factors that in the past did not directly affect either of these states, however, they will be imposed by the importing countries which they supply – mainly EU – if they aspire to continue the expansion of their exporting strategy.

4.5.3 Thailand

Thailand in contrast with the two aforementioned states has followed a completely different path of development. Instead of the highly export-oriented direction of Indonesia and Malaysia, Thailand was adopted a more introvert approach. The production of the country is almost totally utilized for its own consumption without significant volumes of trading with third countries, neither import nor export[151]. Moreover, the production of biofuels is almost evenly separated in bioethanol (45%) and biodiesel (55%). The government of Thailand, since 2005 created several initiatives to support the production and the consumption of both biofuels, with a triple long-term goal of *"improving energy security, enhancing employment opportunities and promoting rural development"*[152].

By setting mandates of biofuel use in the fuels industry as blends of fossil fuels and biofuels, while also supporting the market of eco-cars that are compatible with E20 and E85 gasoline and B5 - B20 diesel making them tax-free, the government increased the national demand for biofuels raising its penetration in the fuel market. It is worth noted that Ethanol had a share of 13.7% in the gasoline market in 2020 when biodiesel was close to 8% in the same year. In this way, Thailand is enhancing energy security through diversification of resources and reducing reliance of fossil fuel imports. In the article it is calculated that a production of 3.1 billion liters could reduce oil imports by $675 million annually. With this in mind, a new target was set in a 20-year Alternative Energy Development Plan (AEDP) 2018 (2018 – 2037), to reach 5,1 billion liters of production by 2037, equally shared to biodiesel (2.9 billion liters) and bioethanol (2.7 billion liters)[153].

Another way that Thailand uses to deploy its strategy, is by providing low interest loans to small farmers of palm trees in order to encourage their development and expansion of their production on more land and additionally modernize cultivation methods to achieve an efficiency of 20t/ha[154]. Similar targets have been set for cassava (44t/ha by 2026 from 22t/ha in 2015), and sugarcane land

[150] USDA - Thailand: Biofuels Annual 2021
[151] USDA - Thailand: Biofuels Annual 2021
[152] Manila: Asian Development Bank 2009
[153] Manila: Asian Development Bank 2009
[154] USDA - Thailand: Biofuels Annual 2021

usage (2.6 million hectares by 2026 from 1.6 million hectares in 2015), that together with molasses are the major feedstock of Thailand's ethanol production. Thus, a boost of the rural development is achieved while simultaneously the creation of employment is supported in the agricultural sector. In this way, compared to Indonesia the land use for palm oil cultivation that is now owned by small farmers, is in a large portion based on *"marginal land areas and old rubber plantations, reducing (albeit not completely cancelling) the need for clearing forested areas"*[155].

Furthermore, the commitments made in the Paris Climate Conference in 2015 are presenting the climate driver that secures and promotes the development of the biofuel industry. Then Thailand set a goal to reduce its GHGs emissions to 20-25% by 2030 compared to 2015 that accounts to about 125 million tons of carbon dioxide. This is becoming reality through the aforementioned policy of (AEDP) as well as four more plans under the umbrella of National Determined Contribution (NDC 2016).

However, although Thailand tries to manage and *"restrict land use change to avoid negative impacts on food crops"*[156] no further sustainability criteria are in place through explicit policies regarding the choice of feedstock – towards more advanced biofuels, land usage, and biodiversity protection. Additionally, in the case of Thailand that is not involved with exporting or importing strategy, such sustainability criteria cannot be indirectly enforced by third countries as in the case of Indonesia and Malaysia, neither by the market as its production becomes less and less competitive compared to other countries in the region.

Therefore, despite its capability to explore alternative feedstocks, biodiesel production is still based on Palm Oil by almost 100% with UCO production reaching a mere 5 million liters out of an almost 2 billion liters of production. In a similar but quite improved situation, bioethanol in Thailand derives form Molasses (54%), Sugarcane (13%) and Cassava (33%) that is considered a second-generation biofuel feedstock.

The production is not growing in a fast pace – an average of 7% in the last decade – as it happens with other countries, nevertheless a steady growth is observed, well planned and driven by several criteria, including sustainability.

4.6 Discussion

Through the analysis, it was demonstrated that the issue of climate change, which is becoming more and more relevant over time, is becoming a stronger motivator for all actors. This may be the result of either their own environmental concerns as happens with China, or due to their commitment to international agreements aimed at reducing GHGs. Nonetheless, although being consistent and vital as a factor, not all of the key players consider it to be the most crucial one.

Energy security and the reduction of energy dependence through resource and supply diversification are the main drivers in developed and developing regions with high energy demands. In cases such as the EU and China, energy is vital to support their economic production

[155] USDA - Thailand: Biofuels Annual 2021
[156] Manila: Asian Development Bank 2009

cycles and the quality of life of their citizens while oil and gas resources are insufficient. Because of this, they are not only content to invest in biofuels production, but also to import significant quantities of biofuel from other producers, playing a significant role in the regulation and certification of the market products. Climate change, may therefore be a significant consideration for both China and the EU, but it ranks second behind energy security.

US which became a leader since 2006 surpassing Brazil in bioethanol production seems to have the most balanced incentives. Being an oil producer and oil exporter since 2008, utilizing the technology of hydraulic fracturing (fracking), they use biofuels as a complementary way to enhance their energy security and to dampen potential shocks in the oil market. Having an extensive agricultural development and a well-established corn production, the advent of the biofuels business is not a game-changer, but it is still an important way to assist this economic sector by generating jobs and promoting rural development. In addition, since they are dedicated to reducing GHG emissions, biofuels are a wonderful way to do so in the transportation sector without having to make tremendous adjustments to the existing infrastructure. Thus, for US biofuels may not be the spearhead of their strategy, however, it is a way to holistically deal with several issues with the same instrument.

The most important factor for developing nations like Indonesia, Malaysia, Thailand, and Brazil is to support their economic growth and their development. Either their economic development through exports of biofuels to more developed importing countries with energy needs not met by their production, as mentioned in the preceding paragraphs, or their rural development through investments in agricultural production to increase the feedstock for biofuels. On the other hand, they can also work to strengthen both their rural and economic development not by increasing exports as in the case of Brazil, Indonesia and Malaysia, but mostly through reducing dependency and oil imports as in the case of the strategy of Thailand.

As far as the impeding issues mentioned in literature are concerned, the major and the most important was the competition for land and resources created between the food and the fuels industry. This may have a greater and more direct impact in developing countries where a larger portion of their population in more exposed in food deprivation and insecurity, however, it is also a concern for more developed economies such as US and EU. Either because they indirectly affect the developing ones, or because they also are getting affected or threatened to be affected. In the EU's instance, investing in energy security must be balanced with ensuring that food security is not jeopardized.

Concerns regarding the production processes and outcomes of biofuels development are another hinderance. Forest fires, deforestation and intensive farming that cause land and water deprivation are issues met in every region but particularly in those with the quickest population growth, such as Malaysia and Indonesia. Biodiversity is also threatened under these circumstances as well, but this is because these areas were more virgin and better-preserved in previous decades. Therefore, this is an issue that will not be confronted directly by every state. However, this may happen indirectly due to the interdependences of the states created in the global market and the regulations that will be posed in this market.

Sustainability is the factor that marks how well each state deals with the aforementioned issues of food vs fuel indexing, production efficiency and the threat of deforestation and loss of biodiversity. And as the biofuel market becomes more worldwide and more developed over the coming decades, such issues will become even more measured and regulated. Thus, sustainability might be a metric that represents the health, stability and potential future growth of each state's biofuel industry in a mature global market.

As mentioned in the analysis, the oil and gas industry continue to dominate the fuel markets because the presence of biofuels is limited to an average of 10 to 20 percent. It is also the one that still has the biggest impact on biofuel development in this relatively early stage of their expansion. Oil price fluctuations stimulate or discourage biofuel production as an interchangeable alternative, however, over time the industry will become better established and more independent, as it happened with the industry of natural gas, and the factors analyzed will get more important for their strategic development.

Chapter 5: Conclusions

5.1 Summary and conclusions

Biofuels' industry is regaining relevance and expanding during these turbulent times in the energy sector where a large transition is taking place. The industry has a number of stakeholders from the outset such as US and Brazil, and others have subsequently joined, especially in the past few decades including China, EU, Indonesia and Thailand. As a result, new networks, synergies and interdependencies are formulated in the industry of biofuels, which will continue to transform and rebalance as it matures and grows.

The analysis done in this paper shows that each producing nation has a range of geopolitical roles in the energy map. Each role is fueled by a unique blend of factors, depending on the standing of each region and each country on the current geopolitical map. After careful consideration of the selected factors, it was found that each one had a special gravity and influence on each state actor. Although all factors were generally applicable to all regions, the differences were clarified through the analysis.

The US might have a balanced interest in all the factors, mostly avoiding the negative ones, but this is not true for all the states. Climate change, is the most applicable to all, however, it is second priority specially to states with more urgent concerns. Energy security, is the most important for nations and regions with vast energy demands and disparate limited energy resources, such as EU and China. All states benefit indirectly from rural development, but those that need to boost their GDP, like Brazil, Indonesia, Malaysia, and Thailand, place more emphasis on it. On the other side, environmental concerns, reemerge as the industry becomes more mature globally. They are met more frequently in more virgin areas but they are getting regulated by the largest importers in the market, primarily EU and secondly China. Deforestation is also met as a concern that affects in a more direct way the production of developing economies like Malaysia and Indonesia. The same happens in the food competition in an even more direct and escalated way. Last but not least, sustainability is the unifying factor that may be utilized to measure the vitality, stability, and expansion of the state-level biofuel industries.

5.2 Limitations and recommendations for further research

Concluding this thesis, it is crucial to discuss the limitations encountered during its preparation. First off, due to the time constrains and the decision to maintain a more constrained, focused scope the study was primarily qualitative. The study utilized a variety of statistical data to identify and compare the key producers, however, no extensive statistical analysis was done as the main focus was to provide a better qualitative understanding of the global status. Then, due to the scope and the extent of the work, there was a selection of the major producing states and regions, rather than a thorough analysis of more and smaller players which might would offer a more in-depth perspective, but could also distort the geopolitical factors that mainly affect the producers. Finally, concerning the selected geopolitical factors, it should be noted that they were the major ones identified in the literature but not the only ones that affect each country's production, as this is the output of a complex economic and geopolitical function of all the active sectors of each state.

In light of this, a few additional topics can be suggested for further study. First of all, a similar study might be carried out based on a statistical comparison across the key states with each state's arable land and economic strength being taken into consideration as a normalization factor. Examining how major energy producers of the oil and gas period, felt about investing in biofuels is another intriguing topic. States such as Russia and UAE that did not appear to be biofuel producers, might be affected by other geopolitical factors, causing them to make alternative decisions throughout this energy transition. Finally, as biofuels mainly thrive in the transportation and mobility sector, a broader scope of work could be a comparative study between biofuels and alternative competitors in the field, such as hydrogen and electricity. In any case, the biofuels sector is a very promising one, and it appears that it will be a major topic in the future energy transition.

Chapter 6: References:

Achinas, S., Horjus, J., Achinas, V., & Euverink, G. J. (2019). A pestle analysis of biofuels energy industry in Europe. *Sustainability, 11*(21), 5981. doi:10.3390/su11215981

Ackrill, R., & Kay, A. (2014). Policy Drivers and Market Challenges. *The Growth of Biofuels in the 21st Century*.

ADB. Integrating Biofuel and Rural Renewable Energy Production in Agriculture for Poverty Reduction in the Greater Mekong Subregion. An overview and strategic framework for biofuel development. In: ADB, editor. Manila: Asian Development Bank; 2009.

Afionis, S., & Stringer, L. C. (2012). European Union Leadership in Biofuels Regulation: Europe as a normative power? *Journal of Cleaner Production, 32*, 114-123. doi:10.1016/j.jclepro.2012.03.034

Agarwal, S., & Kumar, A. (2018). Historical development of biofuels. *Biofuels: Greenhouse Gas Mitigation and Global Warming,* 17-45. doi:10.1007/978-81-322-3763-1_2

Albers, S. C., Berklund, A. M., & Graff, G. D. (2016). The rise and fall of innovation in Biofuels. *Nature Biotechnology, 34*(8), 814-821. doi:10.1038/nbt.3644

Alckmin, G., & Goldemberg, J. (2004). Assessment of Greenhouse Gas Emissions in the Production and Use of Fuel Ethanol in Brazil. *Http://www.unica.com.br/.*

Aro, E. (2015). From First Generation Biofuels to advanced Solar Biofuels. *Ambio, 45*(S1), 24-31. doi:10.1007/s13280-015-0730-0

Azadi, P., Malina, R., Barrett, S. R., & Kraft, M. (2017). The evolution of the Biofuel Science. *Renewable and Sustainable Energy Reviews, 76,* 1479-1484. doi:10.1016/j.rser.2016.11.181

Bekunda, M., Palm, C. A., Fraiture, C., Victoria, R. L., Watson, H., Woods, J., . . . Ravindranath, N. H. (2009). Biofuels in Developing Countries. In *Biofuels: Environmental Consequences & Implications of Changing Land Use* (Vol. Chapter 15, pp. 249-269). Ithaca, NY: Cornell University.

Biodiesel benefits and considerations. (n.d.). Retrieved March 14, 2022, from https://afdc.energy.gov/fuels/biodiesel_benefits.html

Biodiesel blends. (n.d.). Retrieved March 14, 2022, from https://afdc.energy.gov/fuels/biodiesel_blends.html

Bomb, C., McCormick, K., Deurwaarder, E., & Kåberger, T. (2007). Biofuels for transport in Europe: Lessons from Germany and the UK. *Energy Policy, 35*(4), 2256-2267. doi:10.1016/j.enpol.2006.07.008

BP, C., & Looney, B. (2021). BP Statistical Review of World Energy. *70*.

Bradley, R., Baumert, K. A., & Dubash, N. K. (2005). *Growing in the greenhouse: Protecting the climate by putting development first*. World Resources Institute.

Brutschin, E., & Fleig, A. (2018). Geopolitically induced investments in biofuels. *Energy Economics*, *74*, 721-732. doi:10.1016/j.eneco.2018.06.013

Cavalett, O., & Ortega, E. (2010). Integrated Environmental Assessment of biodiesel production from soybean in Brazil. *Journal of Cleaner Production, 18*(1), 55-70. doi:10.1016/j.jclepro.2009.09.008

Crop Genetic Improvement Technologies. (2015, February 26). *European Plant Science Organisation*, (Brussels), 1-3.

Curran, M. A. (2006). *Life-cycle assessment: Principles and practice*. Cincinnati, OH: National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency.

De Oliveira, F. C., & Coelho, S. T. (2017). History, evolution, and environmental impact of biodiesel in Brazil: A review. Retrieved March 14, 2022, from https://doi.org/10.1016/j.rser.2016.10.060

Delshad, A. B., Raymond, L., Sawicki, V., & Wegener, D. T. (2010). Public attitudes toward political and technological options for biofuels. *Energy Policy, 38*(7), 3414-3425. doi:10.1016/j.enpol.2010.02.015

DEMIRBAS, A. (2007). Progress and recent trends in Biofuels. *Progress in Energy and Combustion Science, 33*(1), 1-18. doi:10.1016/j.pecs.2006.06.001

DITZEL, K., VENKATESHWARA, V., O'HARE, K., NYSTROM, S., & NAGLE, M. (2018). THE BIODIESEL INDUSTRY: IMPACTS ON THE ECONOMY, ENVIRONMENT AND ENERGY SECURITY. *FTI Consulting,* 1-29.

Doc. No. Directive (EU) 2018/2001 at Http://data.europa.eu/eli/dir/2018/2001/oj (2018).

Gay, J. E. (2013). Green peace: Can biofuels accelerate energy security. doi:10.21236/ad1018855

Gonzalez, C. G. (n.d.). An environmental justice critique of biofuels. *Energy Justice,* 41-72. doi:10.4337/9781786431769.00010

Harnesk, D. (2019). Biomass-based energy on the move – the geographical expansion of the European Union's Liquid Biofuel Regulation. *Geoforum, 98,* 25-35. doi:10.1016/j.geoforum.2018.09.019

Hazell, P., & Wood, S. (2007). Drivers of change in Global Agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences, 363*(1491), 495-515. doi:10.1098/rstb.2007.2166

Institute for Labor Studies, Ministry of Human Resources and Social Security. (2010, March). Study on Green Employment in China.

Kandasamy, S., Manickam, N. K., Subbiah, K., Muthukumar, K., Kumaraguruparaswami, M., & Venkata Ratnam, M. (2021). Nanotechnology's contribution to next-generation bioenergy production. *Nanomaterials,* 511-518. doi:10.1016/b978-0-12-822401-4.00036-2

Lyons, K., Levett, C., Swann, G., & Gutiérrez, P. (2015, October 28). Indonesia burning: Forest fires predicted to be worst on record. *The Guardian*.

McCarthy, P., Rasul, M., & Moazzem, S. (2011). Comparison of the performance and emissions of different biodiesel blends against Petroleum Diesel. *International Journal of Low-Carbon Technologies, 6*(4), 255-260. doi:10.1093/ijlct/ctr012

Mukherjee, I., & Sovacool, B. K. (2014). Palm oil-based biofuels and sustainability in Southeast Asia: A review of Indonesia, Malaysia, and Thailand. *Renewable and Sustainable Energy Reviews, 37,* 1-12. doi:10.1016/j.rser.2014.05.001

Naik, S., Goud, V. V., Rout, P. K., & Dalai, A. K. (2010). Production of First and second generation biofuels: A comprehensive review. *Renewable and Sustainable Energy Reviews, 14*(2), 578-597. doi:10.1016/j.rser.2009.10.003

Nastari, P. M. (1983). *The role of sugar cane in Brazil's history and economy* (Master's thesis, 1983). Ames, IA: P.M. Nastari.

Paravantis, J. A., Kontoulis, N., Ballis, A., Tsirigotis, D., & Dourmas, V. (2018). A geopolitical review of definitions, dimensions and indicators of energy security. *2018 9th International Conference on Information, Intelligence, Systems and Applications (IISA)*. doi:10.1109/iisa.2018.8633676

Philp, J. (2015). Balancing the bioeconomy: Supporting biofuels and bio-based materials in public policy. *Energy & Environmental Science, 8*(11), 3063-3068. doi:10.1039/c5ee01864a

Puricelli, S., Cardellini, G., Casadei, S., Faedo, D., Van den Oever, A., & Grosso, M. (2021). A review on biofuels for light-duty vehicles in Europe. *Renewable and Sustainable Energy Reviews, 137,* 110398. doi:10.1016/j.rser.2020.110398

Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program; Final Rule / Federal Register: Vol. 75, No. 58 / P. 14669–15320 / March 26, 2010.

Renewable Fuels Association. (n.d.). Annual ethanol production. Retrieved April 4, 2022, from https://ethanolrfa.org/markets-and-statistics/annual-ethanol-production

Sachs, J. (2005). *UN Millennium Project 2005: Investing in development, a practical plan to achieve the Millennium Development Goals: Overview*. London: Earthscan.

Sajid, Z., Da Silva, M., & Danial, S. (2021). Historical analysis of the role of governance systems in the sustainable development of biofuels in Brazil and the United States of America (USA). *Sustainability*, *13*(12), 6881. doi:10.3390/su13126881

Sheil, D., Casson, A., Meijaard, E., Van Noordwjik, M., Gaskell, J., Sunderland-Groves, J., . . . Kanninen, M. (2009). The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know? doi:10.17528/cifor/002792

Smith, J. (2010). *Biofuels and the Globalization of Risk: The biggest change in the north-south releationships since colonialism?* London: Zed.

Sombilla, M. A., Cueno, S. L., Mahfuz, A. A., & Malik, U. S. (2009). *Integrating biofuel and rural renewable energy production in agriculture for poverty reduction in the greater mekong subregion: An overview and strategic framework for Biofuel Development*. Manila: Asian Development Bank.

Songstad, D. D., Lakshmanan, P., Chen, J., Gibbons, W., Hughes, S., & Nelson, R. (2009). Historical perspective of biofuels: Learning from the past to rediscover the future. *In Vitro Cellular & Developmental Biology - Plant*, *45*(3), 189-192. doi:10.1007/s11627-009-9218-6

Stattman, S. L. (2019). Biofuel governance in Brazil and the EU. doi:10.18174/472916

Timilsina, G. R., & Shrestha, A. (2010). Biofuels Markets, Targets and Impacts. *The World Bank Development Research Group Environment and Energy Team, WPS5364*.

Uría-Martínez, R., Leiby, P. N., & Brown, M. L. (2018). Energy security role of biofuels in evolving Liquid Fuel Markets. *Biofuels, Bioproducts and Biorefining, 12*(5), 802-814. doi:10.1002/bbb.1891

USDA (Foreign Agricultural Service), & Barros, S. (2019, September 8). Brazil: Biofuels Annual 2019 RN: BR19029.

USDA (Foreign Agricultural Service), Flach, B., Lieberz, S., & Bolla, S. (2019). European Union: Biofuels Annual 2019 RN: E42021-0053.

USDA (Foreign Agricultural Service), McGrath, C., & Branson, A. (2021). People's Republic of China: Biofuels Annual 2021 RN: CH2021-0096.

USDA (Foreign Agricultural Service), Prasertsri, P., Chanikornpradit, M., & Mullis, E. (2021). Thailand: Biofuels Annual 2021 RN: TH2020-0124.

USDA (Foreign Agricultural Service), Rahmanulloh, A., & Mcdonald, G. (2021). Indonesia: Biofuels Annual 2021 RN: ID2021-0027.

USDA (Foreign Agricultural Service), Wahab, A. G., & Harrison, T. (2021). Malaysia: Biofuels Annual 2021 RN: MY2021-0014.

Vakulchuk, R., Overland, I., & Scholten, D. (2020). Renewable Energy and Geopolitics: A Review. *Renewable and Sustainable Energy Reviews, 122*, 109547. doi:10.1016/j.rser.2019.109547

Wang, R. (1988). Development of biodiesel fuel. *Taiyangneng Xuebao, 9*, 434-436.

www.easac.eu. (n.d.). Retrieved March 14, 2022, from http://www.easac.eu/home/reports-and-statements/detail-view/article/planting-the.html&lang=en

Youngs, H., & Somerville, C. (2012). Development of feedstocks for Cellulosic Biofuels. *F1000 Biology Reports, 4*. doi:10.3410/b4-10

Zhong, C., Cao, Y., Li, B., & Yuan, Y. (2010). Biofuels in China: Past, present and future. *Biofuels, Bioproducts and Biorefining, 4*(3), 326-342. doi:10.1002/bbb.207

Zilberman, D., Hochman, G., Kaplan, S., & Kim, E. (2014). Political Economy of Biofuel. *Choices, A Publication of the Agricultural & Applied Economics Association*, *1st Quarter 2014, 29*(1).