LUND UNIVERSITY
School of Economics and Management

Bachelor's Program in Economy and Society

# The Impact of Policy on the Production of Liquid Biofuels

## A case study on the impact of government policies on the production of liquid biofuels in the U.S.

by

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In the following thesis, the development of the biofuels sector in the United States will be analysed using environmental economics. Around year 2005, there was a significant increase in the production of liquid biofuels. Hence, the thesis aims to explore the reasons behind the increase. Acts of government have been analysed while enlisting the help of summaries and overviews accessed through various government agencies. The findings include the Volumetric Ethanol Excise Tax, the Renewable Fuel Standard, international agreements, price differences between biofuels and oil, and more. The correlation between policy introduction and the growing biofuels sector is established, while simultaneously considering other aspects. The implications of the introduction and removal of various incentives are explored while considering other aspects unrelated to policy. The findings of the thesis can help policy makers make informed decisions and apply the most suitable incentives while considering aspects like costs and public perception.

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# Contents

# List of Abbreviations

| | |
|---|---|
| AJCA | American Jobs Creation Act of 2004 |
| BBD | Biomass-Based Diesel |
| BSM | Biomass Scenario Model |
| CAA | Clean Air Act of 1970 |
| EIA | U.S. Energy Information Administration |
| EISA | Energy Independence and Security Act of 2007 |
| EKC | Environmental Kuznets Curve |
| EPA | Environmental Protection Agency |
| EPAct | Energy Policy Act of 2005 |
| GHG | Greenhouse Gas |
| KB/D | Thousand Barrels per Day |
| KBOE/D | Thousand Barrels of Oil Equivalent per Day |
| MTBE | Methyl Tertiary-Butyl Ether |
| NREL | National Renewable Energy Laboratory |
| RFS1 | Renewable Fuel Standard of 2005 |
| RFS2 | Renewable Fuel Standard of 2010 |
| RIN | Renewable Identification Numbers |
| RIS | Regulatory Impact Analysis of the RFS, done by the EPA |
| USDA | United States Department of Agriculture |
| VEETC | Volumetric Ethanol Excise Tax Credit |

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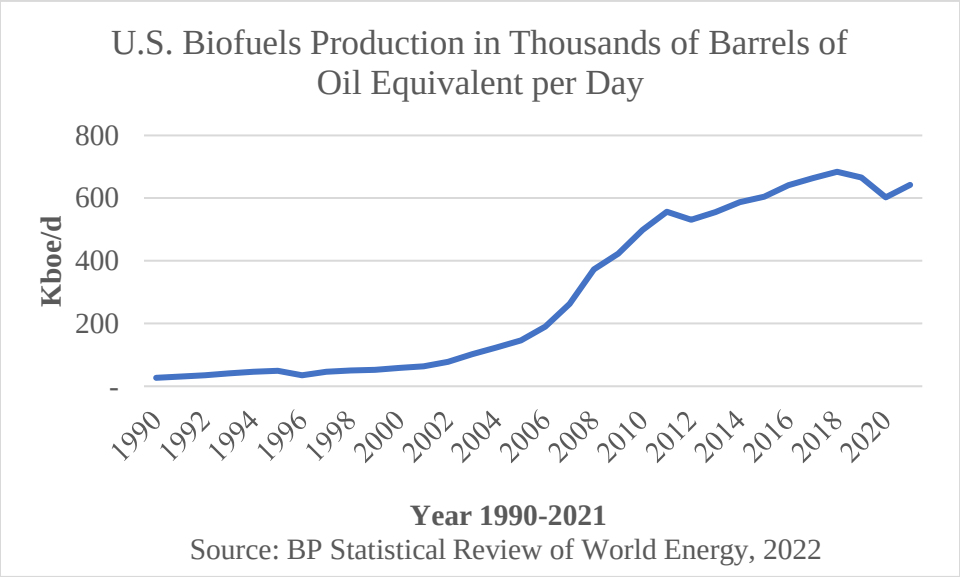
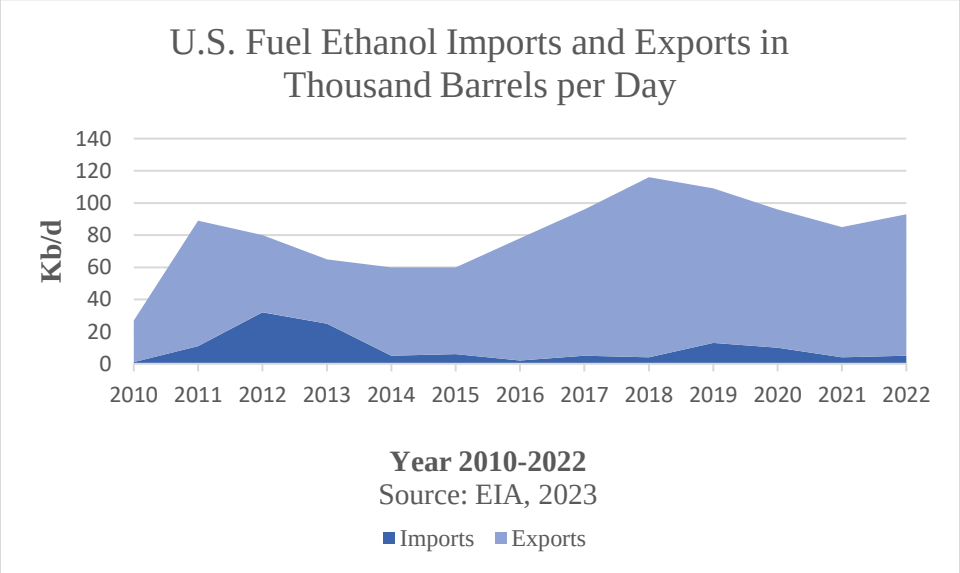
**Figure 1.**



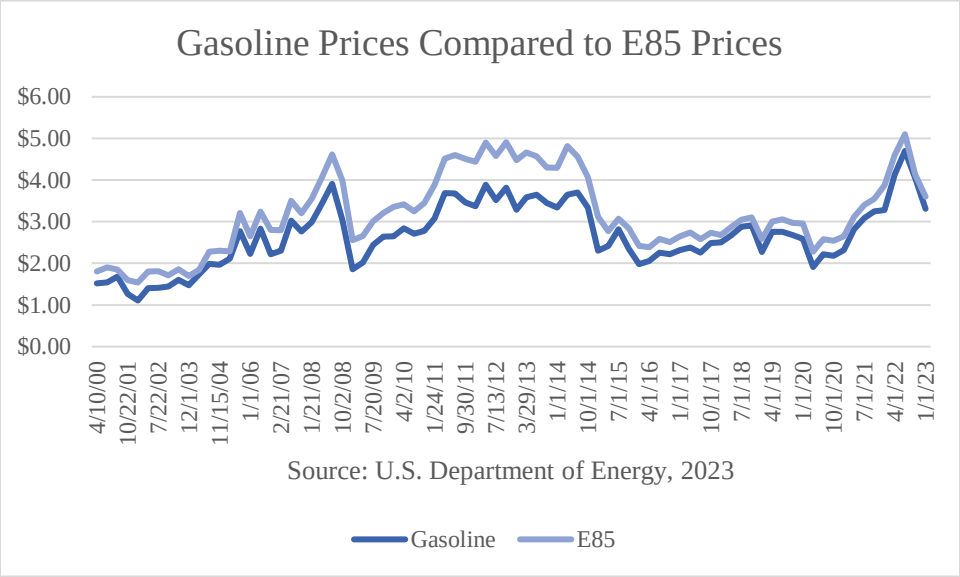

The graph depicts U.S. biofuels production between the years 1990 to 2021 in thousands of barrels of oil equivalent per day.

**Figure 2.**




The graph depicts U.S. imports (light blue) and exports (dark blue) of fuel ethanol in thousands of barrels of oil per day.

**Figure 3.**




The graph depicts historical gasoline (dark blue) prices compared to E85 (light blue) prices in American Dollars from October 2000 to January 2023.

## 1. Introduction

The U.S. is the world's biggest producer of liquid biofuels and has been since 2006 (BP, 2022). In a 20-year period, from 2001 to 2021, the production of liquid biofuels increased tenfold from 64 Kboe/d to 643 Kboe/d, with a significant increase in production happening around 2005 (Figure 1). Kboe/d is thousand barrels of oil equivalent per day. Although all liquid biofuels are accounted for in the graph, ethanol production is responsible for most of the increase (NREL, 2013b; USDA, 2017; Stewart et al, 2023). The increase is likely due to several reasons, including a natural increase in demand, technological advancements, as well as various government incentives. In this thesis, the reasons behind the sharp increase seen around the year of 2005 will be explored. This case study will not only analyse the different government incentives introduced, removed, or edited around this time. It will also review the international regulations, technological advancements, and other reasons behind the increased biofuels production. Furthermore, there wi ll be a discussion aimed at finding out why some incentives were chosen over others and consequently if the policy embodied the most cost-effective and efficient option. Additionally, some of the analysis will be devoted to explaining the rest of the graph, and why production is not increasing as rapidly as it once was. However, it is important to note that the analysis will not be comprehensive as the focus will be on national and international laws, regulations, and targets. During this time, several policies were introduced on a municipal, regional, or state level (Goldfarb & Kriner, 2021; Mazzone et al, 2022). However, given the scope of the thesis they will not be included. Furthermore, some policies not directly introduced to increase biofuels production may still affect production levels.

The introductory chapter will contain all relevant background information, as well as the aim and scope of the thesis. The thesis will then follow a pattern in which relevant theory is presented, and the theoretical approach chosen is introduced. Continuously, there will be a critical analysis of the data used, as well as a discussion of the limitations of the thesis. Following that, methodology will be presented, after which the empirical analysis and discussion follows. In the conclusion, I will explore whether the aims of the thesis were met and give directions for future research.

## 1.1 Background

Under section 201, J of the Energy Independence and Security Act of 2007, or EISA, renewable fuel is defined as “fuel that is produced from renewable biomass and that is used to replace or reduce the quantity of fossil fuel present in a transportation fuel”. The term biofuel refers to all biofuels and can be divided into traditional and modern (Rajagopal & Zilberman, 2008). Biofuels include fuels from all plant-based sources. Moreover, traditional biofuels refer to energy sources such as burning wood, animal waste, and crops (Rajagopal & Zilberman, 2008). Modern biofuels include fuels derived from biomass, such as ethanol. What is being discussed in the thesis is modern, liquid biofuels. Thus, for the purposes of this paper, biofuels, and liquid biofuels will be used interchangeably, always referring to modern liquid biofuels, like ethanol and biodiesel. Biodiesel and renewable diesel are collectively known as biomass-based diesel, or BBD for short (Mazzone et al, 2022).

There are several reasons why an increase in biofuels production is desired. Rajagopal and Zilberman (2008) list the most significant ones. Firstly, biofuels can contribute to increased energy security due to several reasons, including reducing oil-trade with unstable regions and contributing to domestic energy control. Secondly, and perhaps the most cited reason, biofuels can contribute to reduced GHG emissions. Thirdly, unlike traditional petroleum fuels, the resources biofuels are derived from are replenishable. These are the three main points often used to argue for an increased biofuels production. However, Rajagopal and Zilberman (2008) note that there are more, including increased agricultural income, development of new jobs, and more. Therefore, these are not all the reasons why an increase in biofuels production is desirable, but they are the main points mentioned across existing literature. Biofuels exhibit decreased lifecycle GHG emissions compared to petroleum-based fuels, and thus this is the most significant reason behind the most significant reason behind their support. Lifecycle GHG emissions is defined as the following under section 201, H in the EISA: “the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes)”. Hence, lifecycle GHG emissions cover the whole production and consumption process, rather than the burning of fuel alone.

However, it is important to note that there are several significant reasons why the benefit of biofuels has been questioned. One of the most relevant points regard food-security. First

generation biofuels compete with traditional food sources as they are derived from crops such as corn and sugarcane (Milano et al, 2016; Rajagopal and Zilberman, 2008). Not only do the crops themselves provide a threat against food security, as crops could be used for human or animal consumption. But growing them takes place in the same agricultural land otherwise used for food production (Milano et al, 2016; Van Ginkel et al, 2020). Second and third generation biofuels are derived from crops that do not compete with traditional biofuel sources, most notably microalgae, but also animal waste and wooden crops (Li & McCluskey, 2017; Milano et al, 2016). Continuously, they do not compete with arable land or even freshwater supply as microalgae can be grown in saline water, and products such as animal waste is a biproduct of already existing agricultural production (Van Ginkel et al, 2020). However, the technologies needed in order to produce second and third generation biofuels on a large scale are not available at this stage and several advancements are necessary, thus first-generation biofuels are responsible for the significant increase in production seen in Figure 1 (Milano et al 2016).

Now that we know why an increased production of biofuels has been deemed desirable by policymakers, we will explore what tools are available to policy makers. The policies used to promote the production of liquid biofuels can be divided into three main categories: taxes, subsidies, and property rights. These policies can be thought of as the government's tools to encourage corporations to act in a way that is consistent with national and international interests, targets, and regulations.

Neoclassical assumptions of economics are the basis for many models and theories, although they rarely align with reality due to assumptions such as perfect competition, rationality, and more. In the neoclassical perspective, there is no justification for policy as the free market will automatically allocate resources in the most efficient way, in accordance with Adam Smith's famous invisible hand. However, Sterner & Robinson (2018) state that externalities act as a justification for policy introduction. The authors define externalities as "side effects of production or consumption" (p.232). Since externalities cannot be avoided, they are to be mitigated, through policy. Lamers et al (2011) divide government incentives into three categories. In short, the government can promote consumption through consumption mandates, promote production through production mandates, or use protective measures. Protective measures include eligibility requirements, tariffs, and more (Lamers et al, 2011).

Taxes and subsidies that are introduced to deal with externalities are commonly referred to as Pigouvian. A Pigouvian tax aims to internalise externalities by representing the real cost of an externality and can be introduced either on the producer side or consumer side (Sterner & Robinson, 2018). No matter if the tax is introduced on the consumer or producer side, the consumer will cover the extra cost. Conversely, a Pigouvian subsidy can be introduced to mitigate negative externalities or encourage positive externalities. However, the effect of a subsidy may differ if it is applied on the consumer or producer side as producers may take advantage of it by not lowering their prices in line with the full subsidy amount (Mazzone et al, 2022). Both taxes and subsidies have the same end objective, to increase the relative price of pollution, but the government can also increase the relative price of pollution in other ways (Sterner & Robinson, 2018). Other incentives include quotas and requirements, introducing property rights, and more.

## 1.2 Research Problem

Figure 1 shows a significant increase in the production of liquid biofuels in the USA after the year of 2005. However, figure 1 does not show the reasons behind the increase. Hence, the objective of the thesis is to discover what happened to cause the sharp increase in biofuel production. Influencing corporations to make decisions that align with national and international targets is achieved through policy introduction. The analysis will show why some incentives were chosen over others, despite not always being the most efficient or cost-effective option. As this is applicable across nearly all different industries in all different countries, my research methods can be used for further research across several fields of research. Previous research has explored similar topics. However, the objective is usually to analyse policy implications, rather than discovering the reasons behind an increase. Similarly, previous research tends to isolate one policy, which can be beneficial in order to determine efficacy. Nevertheless, there are various reasons behind the increase seen in Figure 1. Thus, to achieve the most thorough understanding behind the reasons, one policy cannot be isolated. Consequently, the benefit of analysing the reasons behind an increase is the possibility to include multiple aspects that would have otherwise been foregone. The results are similar to previous studies although the methodology is different.

To explore my research problem, the main research question is:

- What are the reasons behind the sharp increase in the production of liquid biofuels seen after 2005?

To help me answer the research question, three sub-research questions have been used. They are:

- What government incentives were introduced around 2005?
- What other reasons contributed to increased production?
- Why were these particular policies chosen?

By other reasons, I mean technological advancements, price changes, and other reasons behind demand changes. Changes in demand can be caused by many reasons, but the main reason explored in the thesis is the price difference between traditional fuel sources and biofuel, namely ethanol.

### 1.3 Aim and Scope

The purpose of the thesis is to summarise the significant policies introduced around 2005 in the U.S. that led to the sharp increase in biofuels production. However, as previously mentioned only federal policies and international agreements will be covered in the analysis. This limitation is important to highlight, as there are significant policies that exist on a smaller scale, namely California's Low Carbon Fuel Standard and Oregon's Clean Fuel Program. The analysis will involve a comparison of different policies and their efficiency using existing literature to evaluate choices. The last section of the thesis will provide a conclusion of which incentives have been most significant, as well as future suggestions. Although, the conclusion and suggestions will not be comprehensive due to the qualitative nature of the analysis. Still, the study will act as a collection of relevant acts of government as well as previous research. As such, it will contribute to the current knowledge base and may help policy makers make informed decisions.

The focus of the thesis will be on the U.S., not only due to the abundance of data available, but also because of the interesting production curve seen in Figure 1. Although still increasing, the production growth has somewhat stagnated since 2011. Hence, the focus of the analysis will be from 2005 to 2011, although some of the analysis will be devoted to explaining why production

levels are not increasing at the same rate as previously. Furthermore, since acts of government will be reviewed, they need to be available in English for complete analysis, hence the U.S. is a motivated choice. In order to allow for the most comprehensive analysis, the scope has been large-scale policies. Continuously, focus will be on policies directly aimed an biofuels production and consumption. However, other policies have undoubtedly also affected growth, most notably policy aimed at fossil fuel production and consumption. Hence, fossil fuel subsidies could be removed, taxes introduced, and more could be done to further incentivise biofuels production. However, given the scope of the thesis these policies will not be extensively covered, and focus will primarily be on policies directly affecting the production of liquid biofuels. The scope of the thesis is not large enough to analyse the impact of all individual factors. Hence, the above limitations have been made. The thesis will act more like a summary while concluding the likely reasons behind policy decisions as well as their efficiency to an extent. Of course, the research questions also show why the qualitative approach of collecting, summarising, and analysing existing primary and secondary data sources is the most suitable. Although the main research question aims to explore the reasons behind the sharp increase in biofuels production, some space will be allotted for analysis of the policies with the help of previous research.

## 2. Theory

Theory on policy intervention is plentiful. Thus, in the following section the relevant policies and their applications will be introduced and explained. This will be followed by a short discussion on why some policies are chosen over others, which will be important knowledge for the analysis that will follow in section 5.

### 2.1 Economy and Ecology

There are conflicting views about the ideal path to take regarding economic growth and environmental degradation. Some theorise that economic growth needs to be prioritised while others highlight the urgency of policy intervention. In the following section, theory regarding the dichotomy between the environment, or ecology, and economy will be presented (Wiesmeth, 2022).

In the 1990s, the Environmental Kuznets Curve, or EKC gained popularity (Stern, 2004). The EKC is a theoretical model indicating that with increased economic growth environmental damage will first increase but then decrease, forming the shape of an inverted U (Stern, 2004). Stern (2004) highlight the appeal of the EKC, indicating that economic growth can continue while eventually leading to declining pollution levels. If the EKC held true, there would be no justification for environmental policies as pollution levels would eventually correct themselves, through technological advancements, input changes, the development of complex industries, and more (Stern, 2004). Although initially popular, the EKC has faced some criticism. Stern (2004) outlines that in the cases that the EKC holds true it is most likely due to richer countries exporting polluting industries to poorer nations.

Economic growth is often at the expense of the environment, thus, there is a dichotomy (Brock and Xepapadeas, 2018; Wiesmeth, 2022). Brock and Xepapadeas (2018) highlight the two solutions to the dichotomy. Firstly, the privately optimal solution in which externalities are not internalised. In this case, we achieve the unregulated free market equilibrium. Secondly, the socially optimal solution in which externalities are taken into account and thus internalised. The authors explain that "[the] deviations between the private solution and the social optimum justify regulation" (Brock & Xepapadeas, 2018, p.3). Continuously, Sterner and Robinson (2018) claim that if the market is unregulated there will be an oversupply of negative externalities while simultaneously having an undersupply of positive externalities. In a market with externalities there is market failure, and market failure require policy intervention. Market failures are not uncommon and should be corrected using policy. However, Sterner and Robinson (2018) state that market agents can influence the policy and consequently the wrong policy may be introduced, causing not only market failure but also policy failure. Policy failure compounds the externalities of market failure. Using policies to change prices in accordance with externalities is called setting them to efficient prices (Coady et al, 2019).

There are disagreements as to what rate taxes and subsidies should be set, and how much intervention is justified. Wiesmeth (2022) states that pollution levels do not necessarily need to be zero in order for the outcome to be efficient. Hence, policy makers need to figure out which level of pollution is efficient, which has proven difficult given the many conflicting views and opinions of the public and politicians (Wiesmeth, 2022). Conversely, in The Economics of

Climate Change: The Stern Review (2007), Nicholas Stern outlines the urgency of implementing significant policy now to avoid the costs of climate change. Continuously, Stern (2007) highlights that the costs of mitigating climate change will only increase the more action is delayed.

### 2.2 Different Government Incentives

The first fundamental theorem of welfare economics states that if there is complete information and perfect competition, the economic equilibrium will be Pareto optimal (Luc, 2008). Pareto optimality means that no additional action or allocation would make any individual better off without harming another individual (Luc, 2008). This theorem is also related to Adam Smith's famous Invisible Hand, in which the allocation of resources will automatically reach efficient levels under the free market. In this scenario, there would be no justification for government intervention. However, perfect competition only exists in the case that there are no externalities (Lemieux, 2021), which Sterner and Robinson define as "side effects of production or consumption" (2018, p.232). Hence, there is market failure, in which the equilibrium is not efficient (Wiesmeth, 2022). As such, perfect competition becomes a theoretical concept with few real-life applications.

Continuously, why externalities occur can be explained using some key economic concepts. Lemieux (2021) concludes that most economists agree that an externality is an unintended consequence. The Tragedy of the Commons explains why common resources tend to become depleted. If there is no direct personal benefit of not utilising a resource, the resource will be exploited and eventually become depleted, thus creating a negative externality (Sterner & Robinson, 2018). Consequently, the Prisoner's Dilemma is a specific extension of the Tragedy of the Commons in which there is a dominant strategy that will benefit both party A and party B if done individually. However, when one party chooses that strategy, the other party will be significantly worse off. Thus, to suffer less from the consequences, they too choose the dominant strategy, leading to both parties being worse off than if they both had collaborated (Sterner & Robinson, 2018). The Tragedy of the Commons and the Prisoner's Dilemma are frequently seen phenomena across the economy. In the analysis, real life examples of the Tragedy of the Commons and the Prisoner's Dilemma will be presented.

In their experiments, Ballard and Medema (1993) raise labour income tax in order to finance the subsidy. Conversely, the authors reduce labour income tax when a Pigouvian tax is added in order for total government tax revenue to be the same. Raising or reducing labour income tax is explicit in the experiments. However, in reality it is not always explicit. Still, the principle holds true, although it is not necessarily labour income tax that is affected, but another tax or subsidy may be affected instead. Still, the introduction of taxes often faces public disapproval. Although Ballard & Medema (1993) and Sterner and Robinson (2018) agree taxes are more efficient and generate greater welfare improvement, Sterner and Robinson (2018) highlight that subsidies are often more feasible given public opinion. Moreover, the tax continues to be more effective even when the tax and subsidy are set to the same rate (Ballard & Medema, 1993). One benefit of a tax compared to a subsidy is that the money generated from it can be used to increase positive externalities (Ballard & Medema, 1993; Sterner & Robinson, 2018). For instance, other taxes may be removed, or the money generated can be used to fund programs further addressing the same issue the tax targets (Ballard & Medema, 1993; Sterner & Robinson, 2018). Thus, "Pigouvian tax reduces pollution through an output effect and a direct abatement effect" (Ballard & Medema, 1993, p.210). Moreover, Wiesmeth (2022) highlight that there is no general tax rate that can be efficient for all sectors. A certain amount of GHG emissions cannot necessarily be taxed at the same rate across all industries. This is seen in the acts of government used in the analysis, where several industries are treated exclusively with separate tax rates and tax breaks.

Although significant subsidies exist to encourage growth of the biofuels sector, they are combined with the introduction of property rights. This incentive is based on the Coase theorem, and deals with the Tragedy of the Commons by introducing popery rights to public goods. These property rights often entail limited pollution rights that may be sold and traded between companies. Wiesmeth (2022) differentiates between property rights and subsidies or taxes, stating that the former is based of quantities of a commodity and the latter is a price-based approach. The Coase theorem states that in the absence of transaction costs any allocation of the environmental property rights will be efficient (Wiesmeth, 2022). Moreover, the Coase theorem states that these property rights will lead to a Pareto-optimal allocation of resources (Wiesmeth, 2022).

Some policies aim to solve the dichotomy between economy and ecology by limiting environmental degradation without limiting economic growth. Although the immediate consequence may sometimes be that economic growth is limited, in the long run these policies will lead to alternative, more sustainable, routes of economic growth. However, complicating the application of policies are information deficits (Wiesmeth, 2022). Information deficits can lead to policy lags as consequences are not always known as new technologies and industries develop. Continuously, since externalities are unintended, their presence is not always easy to foresee. Thus, policies can only be introduced once externalities have become apparent, at which point it may be difficult to limit well-established industries in a way that does not limit economic growth significantly or cause public displeasure. Another issue with externalities is stated in the name. As externalities, their impact tends to be independent from the source. Thus, it can be difficult to impose policy as the source is not necessarily affected by the externality, and as such will not support intervention.

### 2.3 Previous Research

Research done by Cha and Bae (2011) show that bioethanol production increased significantly after shock increases in fuel prices. Bioethanol dominates the U.S. biofuels market, although production of biodiesel has also increased significantly (Stewart et al, 2023). Consequently, bioethanol production rose 1.9-2.4 times in a four-year time period between 2007 and 2011 (Cha & Bae, 2011). Biodiesel production has grown less and is still under capacity (EIA, 2021b). Continuously, most biodiesel is exported to the EU where there are more incentives encouraging the consumption of biodiesel (NREL, 2013b).

Second and third generation biofuels are yet to reach commercialisation, as refining is both expensive and complicated (Milano et al, 2016; Stewart et al, 2023). Although initially promising, as they do not threat food sources, second and third generation biofuels are still years, if not decades away from commercialisation (Bibi et al, 2017). However, the U.S. government is not only providing production and consumption incentives, but also support for research and development (Malmedal et al, 2007; Stewart et al 2023). Despite several costly incentives, consumption goals have not been met, and targets have been retroactively lowered by the EPA (Stewart et al 2023). Production has remained significantly lower than expected. Stewart et al

(2023) highlight that production targets for 2020 were reduced from 10.5 billion gallons to 510 million gallons. Hence, production remains at a significantly lower level than expected despite various incentives. However, the potential of third generation biofuels is still highlighted by many (Milano et al, 2016; Singh & Gonzales-Calienes, 2021; Mahmood et al, 2022). With some additional genetic engineering, microalgae-derived biofuels have the potential to become carbon neutral (Singh et al, 2020).

Furthermore, public perception plays an important role in the production and consumption of liquid biofuels. Goldfarb and Kriner (2021) highlight the conflicting results from previous research, stating that some have found the public to have a generally positive perspective on liquid biofuels while other studies have found the opposite. However, public perception largely affects policies as stressed by Sterner and Robinson (2018). Sometimes, the public and other actors can even influence policy makers to the large extent that it leads to policy failure (Sterner and Robinson, 2018).

Mazzone et al (2022) highlight some inefficiencies with existing incentives in the U.S. The authors suggest that blenders do not always reduce prices in accordance with the full amount of the subsidy, thus capturing rents. Dorman (2022) also highlights some issues with the RFS, with the main criticism being aimed at the complicated process in which the EPA determines volume requirements.

### 2.4 Theoretical Approach

No specific model will be used in the analysis, instead I will rely on economic theory. In the discussion, concepts like Pigouvian taxes and subsidies will be discussed extensively. Continuously, to facilitate the analysis I will use Stern (2007) to argue why policy intervention is necessary and how additional incentives could be justified. Conversely, I will use authors such as Wiesmeth (2022) to argue why less incentives may be justified. For most of the analysis into the background and motivation behind the policies, Sterner and Robinson (2018) and Ballard and Medema (1993) will be used to discuss why some policies were favoured above others.

## 3. Data

The BP Statistical Review of World Energy from 2022 has provided the data that has been made into Figure 1, and thus acts as the basis of the analysis. The BP Statistical Review of World Energy of 2022 is the 71st edition and the latest one to be released during the process of writing the thesis. Furthermore, to analyse relevant government policies, official government sources will be used. Namely, Clean Air Act of 1970 (CAA), Energy Policy Act of 2005 (EPAct), and Energy Independence and Security Act of 2007 (EISA). The CAA was responsible for the introduction of the Volumetric Ethanol Excise Tax Credit, VEETC, whereas the EPAct and EISA have contributed to the Renewable Fuel Standard, RFS. These two policies will be the focal point of the analysis. Some other acts of government will be cited, as they also have contributed, but the forementioned are the most significant. Furthermore, to conduct a thorough analysis, several supporting literatures will be used. These literatures describe economic theory, environmental economics, and they analyse and compare different economic incentives. This literature is presented under section 2.

### 3.1 Source Material

The source material has been carefully chosen to include official acts of government, international agreements, and other governmental documents. Alongside the BP Statistical Review of World Energy, these will act as basis for my analysis. In the following section, these materials will be presented.

The BP Statistical Review of World Energy has been released for over 70 years and is a popular and reliable source of data that has been significantly utilised across many different fields of research. It includes consumption and production data of various energy sources in several countries. For my analysis, biofuels production data in kboe/d has been used. U.S. biofuels production data is available from 1990, at which point production was negligible to 2021.

Continuously, the data used to make Figure 2 was accessed through EIA, which is the U.S. Energy Information Administration. EIA is responsible for collecting and analysing independent energy data to facilitate consistent policymaking, increase public understanding, and more. Furthermore, EIA is a government agency, contributing to its legitimacy. Similarly, the data used in Figure 3 was accessed from the U.S. Department of Energy Alternative Fuel Price Report.

The most significant acts of government used are the EPAct, in which the RFS is introduced. Among other things, the CAA outlines the Motor Vehicle Emissions and Fuel Standards, of which the most notable policy is the VEETC. Additionally, the EPAct outlines several policy measures, of which not all are related to liquid biofuels. The relevant policies introduced under the EPAct include consumption and blending requirements, research and development funding, and more. Similarly, the EISA outlines various measures, but the ones relevant for my analysis include funding for research and development and additions to the RFS. Furthermore, the information outlined in the acts can also be accessed in the US code. To facilitate interpretation and analysis, articles from the U.S. Energy Information Administration, EIA, have been used. Continuously, summaries and overviews, such as EPA (2022a) and EPA (2023) have been used for the same purpose. As these articles, summaries, and overviews are provided by government agencies, it ensures the information presented there is accurate and aligns with the acts of government.

Additionally, one part of the analysis centres around international protocols. For this section, focus will be on two agreements, the Kyoto Protocol, and the Paris Agreement. Under the Kyoto Protocol, parties commit to limit GHG emissions. The U.S. is a signatory to the Kyoto Protocol but has failed to ratify. Similarly, the Paris Agreement outlines GHG reduction targets. Once again, to facilitate analysis, supporting documents have been utilised, namely the Kyoto Protocol: Reference Manual, provided by the UN (2008).

For a significant part of the analysis, the Regulatory Impact Analysis of the RFS provided by the EPA (2022a) has been used. As it is provided by a government agency, the data presented is accurate. However, the conclusion may be biased. The RIS reaches some positive conclusions about the impact of the various government policies. However, to an extent, this is an expected outcome. Given the extensive support for biofuels production mainly consists of subsidies and tax breaks, they have been very costly. Therefore, reaching increasingly negative conclusions about policy impacts could lead to public dissatisfaction. Since the introduction of the RFS coincides with a period of rapid growth, it is both easy and desirable for the EPA to reach the conclusion that it has been effective. However, independent authors have also analysed the impact of the RFS and reached conflicting conclusions. Thus, in order to eliminate as much bias as possible, their conclusions will also be used for part of the analysis. These authors include Cha

and Bae (2011), Kesan et al (2017), Malmedal et al (2007), Mazzone et al (2022), Newes et al (2022), and Stewart et al (2023).

### 3.2 Limitations

The research conducted faces some limitations. The thesis will not be able to conclude to what extent policy intervention has been effective. This is due to the qualitative nature of the analysis. Furthermore, it is difficult to isolate the different aspects that have affected the growth of the biofuels sector in the U.S. As the analysis will show, there are several factors that have contributed to increased production of biofuels in the U.S. Still, all factors will not be covered. As mentioned under section 1.3 Aim and Scope, the research is limited to national policies and international agreements, however, some state policies have been significant, and they will not be covered in the analysis. Continuously, one of the most notable aspects that will not be covered is to what extent petroleum fuel policies affected their prices and thus the growth of biofuels production. It is not feasible to cover all aspects that have contributed to growing biofuels production in a study of this size. Hence, the focus stays on federal policies and international protocols aimed directly at biofuels throughout.

Furthermore, neoclassical economic models do not consider all aspects of the market. They often assume perfect competition and no information deficits to simplify analysis. Thus, they do not serve a purpose when externalities, imperfect competition, and information deficits are the focal point of the analysis. Continuously, more advanced models like the Biomass Scenario Model, BSM, are outside the scope of the thesis. Furthermore, the BSM is more suitable when analysing a single policy, rather than the reasons behind increased production (NREL, 2013a). Thus, no specific model has been used in the analysis, which instead relies on different economic theories. Furthermore, the qualitative nature of the analysis will not allow for a causational relationship to be established. However, a correlational relationship can be, and the likely causation will be discussed.

## 4. Methods

The thesis is a qualitative case study on U.S. biofuels production. The data used for the analysis has been accessed through official U.S. government websites and through U.S. code. Firstly,

using the sources presented under section 3, the different policies and their applications will be introduced. Although acts of government act as the basis for analysis, summaries and overviews have been used extensively to facilitate analysis. Following that, there will be a policy analysis, which involves a comparison of policies and the intention behind them. To do this, the sources presented in section 3 will be analysed using the theory presented in section 2. In the results, the policies are first presented, and are discussed and analysed extensively under section 5.2. Significant analysis is devoted to exploring the reasons why one policy was chosen over the other, and what the consequences of each policy may have been, both in terms of biofuels production and economic costs.

The qualitative approach is most suitable given the multitude of aspects responsible for the growth presented in Figure 1. The analysis will provide a correlational relationship, as well as establish likely causality. Finally, the main takeaways will be discussed and suggestions for future policy and research will be made.

# 5. Empirical Analysis

## 5.1 Results

The data from the BP Statistical Review of World Energy of 2022 has been made into Figure 1, and the data from EIA (2023) has been made into Figure 2. The figures can help the reader visualise the content and it may be helpful to go back to see exactly how the production curve looks.

In the following section, results will be presented. The results are divided into four sections, of which the first two represent the most significant policy introductions, the VEETC and RFS. Continuously, the last two sections will cover international agreements and reasons unrelated to policy. Finally, it will be followed by a discussion in which the policies are compared. In the discussion, the reasons behind why these incentives were chosen will be covered. Continuously, there will be a section discussing their likely impact on biofuels production levels in the U.S.

### 5.1.1 Volumetric Ethanol Excise Tax Credit

The VEETC has existed for multiple decades with varying levels of support, but for the purpose of this paper the VEETC from 2004-2011 is analysed. In 2004, the VEETC was revised under the American Jobs Creation Act, AJCA. Bielen et al (2018) note that the VEETC is the costliest subsidy in recent American history. As such VEETC was the leading source of monetary support for biofuels from when it was enacted in 2004 to when it expired in 2011 (Sorda et al, 2010). The VEETC expired in 2011, hence it was present during the period of intensely increasing biofuels production. Consequently, the removal of the VEETC also coincides with a production decrease seen in Figure 1.

The VEETC outlined a $0.45 per gallon subsidy and was originally set to expire in 2010, although it was extended to 2011 (IEA, 2012; Bielen et al, 2018). The VEETC also outlines tax breaks for biodiesel production (AJCA, 2004). However, Bielen et al (2018) highlight some issues with the VEETC, including that a large portion of the subsidy likely benefited blending companies, or petroleum refiners. Blending is when ethanol is combined with refined petroleum to create gasoline (Bielen et al, 2018). On an even larger scale, these companies may also be the same to produce ethanol. Thus, the larger part of the whole subsidy may benefit a singular company if that company, like Valero, is responsible for multiple steps in the production line (Bielen et al, 2018). This is because they were able to capture rents by not decreasing prices by the entire amount of the subsidy (Bielen et al, 2018).

Additionally, the VEETC also outlined an import tariff on ethanol that simultaneously ended in 2011. Not only did this protect the domestic market, but it prevented corporations from taking advantage of the tax break by blending imported ethanol (Lamers, 2011). The import tariff was an ad valorem tax set to 2.5% (USDA, 2017). The import tariff mainly protected the U.S. from Brazilian imports, as Brazil is the world's second largest producer of liquid biofuels, and consequently the source of most U.S. imports (USDA 2017; Figure 2). Figure 2 shows a sharp increase in Brazilian ethanol imports in 2011 which coincides with the removal of the VEETC and simultaneously the import tariff. However, since then, despite the removal of the import tariff, imports have continued to decrease. This is likely due to the increased production in the U.S. that alone could cover the increased demand. Additionally, as outlined by the USDA in 2017 and the EIA in 2021a, the U.S. is a net exporter of bioethanol, while simultaneously being a net importer of biodiesel (Figure 2). Nonetheless, some tariffs could be avoided through

dehydrating the ethanol in countries in the Caribbean that have trade agreements with the U.S (NREL, 2013b). Brazilian ethanol has also historically been cheaper than American ethanol due it being derived from sugarcane rather than corn (NREL, 2013b). Hence, imports remained to an extent despite tariffs, which explains Figure 2. Although the VEETC was extended for one year from its original end date in 2010, it was eventually removed in 2011 due to the introduction of the RFS.

### 5.1.2 Renewable Fuel Standard

The RFS was first introduced with the EPAct of 2005, which is an amendment of the CAA, and has since been revised. Although the RFS was created in 2005, EPA (2022a) note that the program did not begin until 2006. The RFS outlines several policies aimed at increasing biofuels consumption. Notably, the RFS mandates minimum blending levels, like the VEETC, along with requiring minimum consumption levels of biofuels (Bielen et al, 2018; Kesan et al, 2017). Although there was initially a distinction made between RFS1 introduced under the EPAct in 2005 and the RFS2 revised under EISA in 2007 and ratified in 2010, they are generally referred to as RFS only and will be referred as such in this thesis (Kesan et al, 2017). However, under RFS2 advanced biofuels producers and standard biofuels producers are required to reduce life-cycle greenhouse gas emissions by minimum 50% and 20% respectively (Sorda et al, 2010). This could perhaps have contributed to the slight decrease in production seen around 2010, due to having to adopt more environmentally friendly methods that were perhaps more inefficient (Figure 1).

There are four renewable fuel categories outlined in the RFS: BBD, cellulosic biofuel, advanced biofuel, and total renewable fuel, collectively referred to in the thesis as liquid biofuels (EPAct, 2005). The different fuels have different production and consumption targets, which the EPA sets through Renewable Volume Obligations, or RVOs annually (EIA, 2022; EPA, 2023). The RVOs outline targets that mandated parties must comply to by producing and blending adequate amount of biofuels or by using Renewable Identification Numbers, or RINs. However, even when the RVOs are set, the EPA has the authority to waiver them, even retroactively. This happened during the impact of COVID-19 (EPA, 2022a). They were retroactively lowered when mandated parties failed to reach the targets (EPA, 2022a). Reasons behind the failures to reach

goals are many. It is undoubtedly difficult to project market activity, especially in a time of crisis, like during COVID-19. But it is also a case of how the data is presented using the credit system, which will be presented in the next paragraph.

The RINs are a credit system used to analyse compliance with RFS. RINs are generated to the producer when one gallon of biofuel is produced (EPA, 2023). The RINs identify what parties are allowed to benefit from subsidies and tax breaks while permitting those who do not identify to keep their business practices without government support and can be obtained either on the market or attached to a biofuel (EPA, 2022a, EPA, 2023). It is required that petroleum importers and oil refiners buy RINs for every gallon of diesel or gasoline that is supplied on the U.S. market, acting like an implicit tax (Mazzone et al, 2022). Continuously, once the fuel has been blended, the RIN can be sold, thus acting like an implicit subsidy on biofuels (Mazzone et al, 2022). The EPA states that ”[obligated] parties have the flexibility to use RINs representing renewable fuel produced in the previous year, often called “carryover RINs” or “banked RINs,” to demonstrate compliance rather than by using RINs representing current year renewable fuel production” (2022a, p. 5). Conversely, if the producer has no carryover RINs and instead fails to meet the targets, the deficit has to be made up in the next consecutive year (EPA, 2023). Unlike the other policies outlined in the RFS, the RINs are examples of a property right as outlined by Wiesmeth (2022) and first suggested by Coase in his famous paper The Problem of Social Cost from 1960.

The EIA (2022) outline two reasons why RIN prices increase. Firstly, if the cost of biofuels exceeds the cost of the petroleum it is blended with, blenders will offset this cost by selling RINs at an increased price. Secondly, if the targets set by the EPA are higher than what market-driven consumption can hold, then RIN prices will increase in line with their increased demand. Mazzone et al (2022) conclude that due to the inclusion of credits (RIN) that can be sold, blenders are willing to pay the higher price of biofuels compared to conventional fuels, in which case they would need to obtain an RIN on the market. Thus, RINs increase demand for biofuels.

However, the system can result in inaccuracies in the data. As RINs may be carried over to the following year, production levels may be higher than the data suggests. Consequently, if banked RINs are used the following year, production levels may be lower than the data suggests. This too leads to difficulties for the EPA when determining RVOs. Additionally, if there are many

carryover RINs, blending requirements may need to be increased. Additionally, RIN prices have continually increased, indicating a high demand for RINs (EPA, 2022b). If the demand for RINs is very high, it indicates that mandated parties are failing to reach requirements through blending. If this is the case, RVOs may be set above production capacity.

Additionally, the EISA outlines various incentives for increased biofuels production. The EISA outlines support for advanced biofuels, which include ethanol derived from various sources, including but not limited to cellulose, sugar, and waste material, as well as biomass-derived diesel, biogas, butanol, and other fuels extracted from cellulosic biomass. Moreover, there is a second-generation biofuel producer tax credit. Under specific conditions, producers are entitled to a $1.01 per gallon tax credit (U.S. Department of Energy, 2022). If the biofuel also qualified under the alcohol fuel tax credit it was reduced to $0.41 or $0.46 per gallon. Although this subsidy is set to a higher rate than the VEETC, it was not as costly as production of second-generation biofuels was relatively low compared to first-generation biofuels.

However, the RFS does not only outline ethanol mixing requirements for gasoline, but it also provides loan guarantees for entities developing new technologies intended to lower GHG emissions (EPAct, 2005). This has contributed to the development of third generation biofuels Moreover, not all funds made available through the RFS are allocated to existing corporations, but some are allocated to research and development (Malmedal et al, 2007). Further contributing to the development of second and third generation biofuels.

However, it is important to note, the ethanol industry long predates the RFS. While increasing production coincides with the introduction of RFS, Kesan et al (2017) note that a significant reason for the increase is likely due to the phasing out of Methyl Tertiary-Butyl Ether, MTBE. MTBE and ethanol were largely used for the same purposes, to help gasoline burn more cleanly (Kesan et al, 2017). Still, producers preferred MTBE as it was less costly (Kesan et al, 2017). But unlike ethanol, MTBE had severe environmental consequences (Kesan et al, 2017). Kesan et al (2017) note that MTBE was phased out due groundwater contamination, but that the VEETC and RFS likely helped support the shift from MTBE to ethanol.

#### 5.1.3 International Protocols

International regulations likely played a role in the increased biofuels production. International agreements outline broader goals that national governments can then target trough policy. For example, the Kyoto protocol introduced limitations to GHG emissions, but regulations to specific industries were up to each party to determine independently (UN, 1997; UN, 2008; Wiesmeth, 2022).

The Kyoto protocol was adopted in 1997, however, given a lengthy ratification process it did not come into effect until 2005 (UN, 1997; UN, 2008). The Kyoto protocol outlines guidelines and goals to limit GHG emissions in industrialised countries (UN, 1997; UN, 2008). However, the Kyoto protocol only outlines goals, and it is up to individual countries to outline specific policy changes to reach the goals. Therefore, the Kyoto protocol may not have directly contributed to the increased production of liquid biofuels in the U.S., but it may have acted as a motivator to enact the EPAct of 2005 and consequently the RFS. Under the Kyoto protocol, countries are required to account for their progress, hence it is necessary that they make policy changes in order to reach goals (UN, 2008).

Additionally, other international agreements such as the Paris Agreement and Glasgow Climate Pact likely influenced federal policies. As agreements such as the forementioned only outline GHG reduction goals it is up to individual nations and actors to discover how to achieve said goals. Although the Paris Agreement and Glasgow Climate Pact contribute to policy changes in the same way outlined for the Kyoto Protocol, they are not covered in the analysis given they were introduced in 2015 and 2021 respectively.

#### 5.1.4 Reasons Unrelated to Policy

Figure 1 indicates that natural market principles and technological advancements likely played a large role in the sharp increase around 2005. This is given that RFS did not come into effect until 2006. Thus, the sharp increase seen already the year before is likely given the phasing out of MTBE as well as the effect of the VEETC. Rajagopal and Zilberman (2008) highlight two possible reasons why the production of biofuels in the U.S. has increased rapidly. The authors state that increasing income in the developing world increases demand for fuel. This alone is one reason to increase biofuels production as traditional fuels come from oil, a depletable resource. Consequently, due to increasing demand, fuel prices are also rising, providing an opportunity to

continue exploring biofuels (Rajagopal and Zilberman, 2008). Continuously, the EPA (2022a) states that demand for petroleum fuels decreased due to many reasons, including the great recession, increased crude oil prices, improved fuel economy of vehicles, and increased use of electric vehicles. Cha and Bae (2011) also conclude that oil prices had a significant impact on the production of ethanol by increasing demand. However, at the same time raising the price for corn, affecting it as a food source (Cha & Bae, 2011). Although, the authors also highlight that short term impact can significantly differ from long term impact. In their research, they analyse the immediate effect of an oil price shock during the financial crisis of 2008. However, given the continuous rise in biofuels production, this cannot be attributed to a single event, or a single shock, although it clearly contributed.

Newes et al (2022) conclude that price competitiveness is the main reason for the significant rise in ethanol production in the U.S. However, Figure 3 shows that E85 has consistently been slightly more expensive than gasoline. Since the introduction of the RFS and consequent blending requirements, all gasoline contains 10% ethanol. Contrastingly E85 contains 85% ethanol. If price competitiveness was the reason behind the significant growth of the biofuels production industry, E85 prices should be lower than E10, as E85 contains significantly more ethanol. Consequently, it is very interesting to find that the data is not in line with Newes et al's (2022) conclusions. The conflicting results are likely due to the different methodology. Newes et al (2022) use a version of the BSM for their study, and as such their research takes all steps of production into account rather than just the finished product seen in Figure 3.

Furthermore, it is crucial to note that other tax breaks or policies not directly related to biofuels or energy in general may have contributed to the increase in biofuels production. For example, section 2 of the AJCA outlines an extension of the possibility to make deductions for depreciable assets for small businesses as defined in section 179 of the Internal Revenue Code of 1986. However, these incentives should not affect biofuels production noticeably more than they affect the production of other goods and the provision of services, but it is possible that policies like these have contributed to the growth of the sector. Nevertheless, given these incentives are available for a multitude of sectors, and not just for biofuels, they have not been covered in the analysis.

Moreover, one reason why the biofuels production curve has stagnated since 2010 could be because of the decreasing petroleum prices. Goldfarb and Kriner (2021) with the help of Bureau of Labor Statistics state that gasoline prices significantly decreased from $4 per gallon in May 2011 to $2.50 per gallon in February 2020. However, also important to note is that biofuels prices do not have to be the exact same as petroleum prices in order to be competitive. A study conducted by Li and McCluskey (2017) shows that consumers are willing to pay up to 11% more for biofuels compared to traditional fuels, which is a significant number.

Public perception is a significant contributor to policy implementations. Public perception not only affects public decisions, but it also affects the decisions of policy makers and politicians. Thus, one could argue that public perception is the most significant contributor to biofuel production increase, as it affects both policy and international agreements. Public perception indicate what policies are feasible. Although the effects of public perception on supply are mostly indirect, it is a direct source behind demand changes.

### 5.2 Discussion

Both the VEETC and the RFS coincide with the period of rapid growth in the biofuels production industry. Hence, it would be easy to draw the conclusion that they both helped significantly. However, the following section will analyse and discuss if that is what happened, or if it is a coincidence that they were introduced during a period of already intense growth. Additionally, since the RFS program did not begin until 2006, it is important to note that the more rapid growth started even before then.

One reason why biofuel production has not reached the targets set out in the RFS is the decreasing demand for gasoline. The EPA had projected that gasoline demand would continue to increase and had thus set their targets in accordance with this assumption (EPA, 2022a). However, given the increased usage of electric vehicles, gasoline demand is likely to continue decreasing rather than increasing.

With the threat that the production of liquid biofuels is to food security, one of the most beneficial decisions outlined in the EPAct is that of loan security. The loan security is provided to entities developing innovative technologies dealing with carbon capture, GHG emissions, and

more (EPAct, 2005). Thus, the loan security has likely contributed to the rapid development of third generation biofuels.

The RINs are a clever way of funding a subsidy, by simultaneously taxing petroleum refiners. Also, since the tax is indirect, it does not face as much public criticism as a direct tax might. In their experiments Ballard and Medema (1993) raised or lowered income tax in order to fund a subsidy or make up for another tax. However, the RINs show that affecting income tax is not the only option.

With the introduction of the RFS, the VEETC could be removed. In a way, the RFS has been more successful than the VEETC, because it achieved the same goal while being a lot less costly. During the period between 2006 and 2011 when both the RFS and the VEETC existed production significantly increased (Figure 1). This is likely because of refiners were able to benefit from the blending requirements as they not only had to do it but also got $0.45 per gallon for doing so. This could be considered policy failure as the VEETC was very expensive and did not necessarily achieve anything the RFS did not. Additionally, the USDA (2017) questions the desirability of an import tariff on ethanol. They state that given the low tax rate combined with decreased imports contributes to a low revenue stream, while administration costs stay high.

The Environmental Protection Agency released a Regulatory Impact Analysis in 2022. In their analysis, they highlight that prior to the introduction of the RFS, there were already several statutory changes being made, namely phasing out MTBE. EPA (2022) state that by the end of 2006, the use of MTBE-blending in gasoline had decreased by 80% compared to the year before. By 2007, the remaining MTBE use was negligible. Consequently, MTBE was replaced by ethanol (EPA, 2022a). Therefore, the rapid increase seen even before the introduction of the RFS in 2006 is most likely due to ethanol replacing MTBE in gasoline blending. In fact, EPA (2022a) conclude that despite ethanol production increasing rapidly, it was not able to keep up with demand and consequently its usage reduced in other areas.

Furthermore, the EPA (2022a) state that the price of biodiesel has been significantly higher than the price of regular diesel, even after accounting for the significant nation-wide $1 per gallon tax credit. Thus, through their analysis, the EPA conclude that the amount of biodiesel produced in absence of the RFS would be negligible. Hence, in order for the demand for biodiesel to increase from market mechanisms alone, the price of petroleum diesel would have to significantly

increase. Otherwise, there would have to be significant improvements in production technologies to decrease prices of biodiesel to a level that is competitive with petroleum diesel prices. However, the EPA (2022a) further state other advanced biofuels and cellulosic biofuels would likely still be produced, albeit not at the same levels. However, as previously stated, biofuel prices do not need to reach the same levels petroleum fuels to be efficient given there is a willingness to pay up to 11% more for biofuels (Li & McCluskey, 2017). Continuously, the EPA (2022a) highlight that biodiesel production remain under capacity, indicating that the RFS has not been fully effective. Thus, biodiesel production is limited by factors other than production capacity (EPA, 2022a). This is likely due to that biodiesel production is very expensive, hence, the market for these fuels is small,

Moreover, the NREL (2013b) state that biodiesel demand in the U.S. has been limited, likely due to the focus of existing policies being on promoting the production and consumption of ethanol rather than other types of biofuels. Consequently, most of the biodiesel produced in the U.S. is exported to the EU given there exists mandates for biodiesel consumption. Also, unlike ethanol, there is no import tax on biodiesel, which is likely a contributor to the low production rates. Furthermore, the NREL (2013b) states that the pattern seen in the U.S., with several policies targeting ethanol production and consumption while simultaneously lacking in policies promoting the production and consumption of biodiesel, is not unique to the U.S.

Hence, the policies are likely driven by international targets set by agreements such as the Kyoto Protocol and the Paris Agreement. Continuously, ethanol production and blending are more established industries compared to biodiesel, which is one likely reason why mandates remain high in that area. They are deemed more cost effective. Wiesmeth (2022) outlines how the Kyoto protocol can be discussed through the Prisoner's dilemma. The author states that a country may benefit from not cooperating with the agreement, as they still benefit from other countries reducing their emissions while gaining a competitive advantage in industry by not slowing down. In line with what Wiesmeth (2022) discusses is the behaviour of the U.S. The U.S. is a signatory to the Kyoto protocol but have not ratified, thus they benefit from everyone else lowering their emissions while simultaneously gaining a competitive advantage in industry. Therefore, the Kyoto protocol is unlikely to have affected the production increase of biofuels in the U.S.

Indeed, the government must consider many aspects when implementing policies. International regulations and agreements that the U.S. are party to need to be considered firstly. But secondly, it is difficult for politicians to implement effective policies that will simultaneously please the public as outlined by Ballard and Medema (1993), and Sterner and Robinson (2018). Additionally, information deficits make policy introduction even more challenging (Wiesmeth, 2022).

Examples of notable programs that have undoubtedly affected the production of biofuels in the U.S. but have not been incorporated in the analysis include California's Low Carbon Fuel Standard and Oregon's Clean Fuel Program. They were not included because they were state based policies, however, they are still important to mention as their impact is determined to have been significant (Mazzone et al, 2022).

The research shows several policies have been enacted, and all have affected biofuels production to a different extent. Nonetheless, before future policies are enacted it is important to fully take into consideration all the externalities of biofuels production. The most important aspects are those of food security, and future policies should prioritise the development of second and third generation biofuels rather than supporting traditional ethanol derived from corn, and other food sources. Continuously, pushing for increased biofuels production may not be necessary given the rapid development of electric vehicles. In conclusion, enacting policy is no easy task as several considerations need to be made. Public perception is also important. Hence, it explains why subsidies have been the most popular approach, although Ballard and Medema (1993), and Sterner and Robinson (2018) conclude that taxes are more efficient than subsidies even when set to the exact same rate.

# 6. Conclusion

## 6.1 Research Objectives

The objective of the thesis was to discover what nationwide policies were enacted in the early 2000s that contributed to the rapid growth of the biofuels industry in the U.S. Federal policies were affected by international agreements, and hence they were also covered. However, policy introduction was not the only reason behind the extensive growth of the industry, and thus changes in demand were also covered. Continuously, the polices were explored through the lense

of environmental economics to find out the reasons behind their implementation and the implications of them.

The research objective was met in that the reasons behind the increase were explored, and their implications discussed. The qualitative nature of the research allowed for multiple aspects to be analysed. However, given the multitude of aspects covered, they were not extensively explored. Continuously, some aspects that undoubtedly affected the production of liquid biofuels were not extensively covered, although mentioned. These include the phasing out of MTBE, state level policies, and policy aimed at affecting the prices of petroleum-based fuels.

In the time frame covered, ethanol production increased the most, while biodiesel production remained relatively low, although it also increased. This is due to most incentives being aimed at increasing ethanol production. These incentives included both blending requirements and tax breaks. Ethanol has been the focus of policy as the ethanol industry was already established, and more cost-efficient than other biofuels. Additionally, demand for biodiesel is relatively low in the U.S. Therefore, most biodiesel is exported to the EU. However, the RFS also outlines funding for research and development, contributing to the development of second and third generation biofuels. Although the production of biofuels is not growing as rapidly as it was, with continued funding for research and development, new technologies that allow for cheaper production will evolve and biodiesel too will become competitive.

### 6.2 Practical Implications

The USDA (2017) states that the U.S. production of ethanol is sufficient to cover the federal market. That combined with the low tariff rate makes income from the ethanol import tariffs negligible, while administration costs remain significant. Thus, the importance of a tariff can be called into question. However, in terms of public perception, a tariff is favourable as it protects the federal market while simultaneously bringing in tax revenue.

Although subsidies are costly, they too tend to be favoured by the public. As such, subsidies have been removed but consequently reinstated retroactively. Hence, the subsidies outlined under section 5.2.1 remain. Subsidies will likely continue to remain as the prices of biofuels are not competitive. However, ethanol subsidies could likely be removed assuming blending requirements persist. Continuously, the EPA could continue setting RVOs, and thus RINs would

remain. Although RINs act as an indirect subsidy as outlined by Mazzone et al (2022) they simultaneously act as an indirect tax for petroleum-based fuels. Consequently, they pay for themselves while still providing an incentive to produce and blend ethanol while also taxing a polluting industry. If RINs and blending requirements remain, other subsidies could likely be removed without affecting ethanol production significantly.

While considering biofuel incentives, policy makers need to compare the cost of a policy to its benefit. Thus, there are some aspects they need to consider. Firstly, the necessity of biofuels has been called into question. The main consumer of oil consists of the transportation industry, however with considerable advancements being made regarding electric vehicles the oil usage of the transportation industry is predicted to decrease. Yet, it has proven difficult to replace jet engines with batteries, due to their weight and some safety concerns (Sripad et al, 2021). Consequently, a significant market for ethanol should remain now and for the foreseeable future. Therefore, incentives are still justified in this instance. The other significant aspect to consider is that of food security. U.S. ethanol is mostly derived from corn, but also other food sources. Hence, increased ethanol production contributes to increased food prices. This is another reason why one could argue for the removal of import tariffs as Brazilian ethanol is derived from sugar cane. Therefore, Brazil tends to export ethanol when sugar prices are low. Although sugar is also a food source, it does not contribute to food insecurity in the same manner as sugar is an additive rather than a necessity. The case of food insecurity is an argument as to why more funding and loan guarantees should be allocated towards research and development rather than ethanol, as second and third generation biofuels do not compete with food sources but have not reached commercial levels yet. Continuously, third generation biofuels have the potential for even lower lifecycle GHG emissions and hence their development should be prioritised. If biofuel policy contributes to increased food prices that could be regarded as policy failure.

It is difficult, even using complex models to determine the effect of the different policies. The policies not only interact with production data, but they interact with each other and affect many other aspects. Additionally, the many different aspects unrelated to policy further complicate the process of determining policy effect. Continuously, the other policies not included in the analysis have also undoubtedly affected increased biofuels production. Especially, increased taxes and

thus increased price of fossil fuels have likely contributed to the growth of the biofuels industry by increasing demand.

## 6.3 Future Research

Many different aspects have affected the growth of the biofuels industry in the U.S., and as such it is difficult to determine the efficacy of policies and their implications. As the thesis provides a general overview that is very broad, future research could focus on a specific policy and analyse results using empirical methods. Although this has been done extensively, past researchers have reached conflicting results. While some authors, like EPA (2022a) have concluded that the VEETC and the RFS have been highly effective, authors such as Newes et al (2022) determine that the main reason behind the increase is due to the price differences between ethanol and oil. However, the price of E85 has consistently been higher than E10. Yet, Newes et al (2022) analyse prices available to refiners rather than consumers and that is likely where the price discrepancy comes from. Continuously, authors such as Bielen et al (2018) have concluded that the VEETC may have been taken advantage of by blenders not lowering prices by the full amount of the subsidy. Hence, continuous research is necessary to establish what policies should be continued, discontinued, or introduced. For future research, different methods, such as the BSM, can be used to discover exactly how efficient certain incentives have been. Analysing past efficiency of existing incentives allows policy makers to make informed decisions based on what has previously worked. Hence, my research in combination with other research can help policy makers determine what policies work and what policies were less effective, and hence know what policies should be implemented in the future. They will also gain greater knowledge about what factors come in to play when choosing policies. Although authors such as Cha and Bae (2011) have analysed the impact of increased ethanol production on food prices, continuous research is necessary to determine at what rate subsidies and taxes should be set as to not cause policy failure.

## 6.4 Chapter Summary

The biggest takeaway of the research is that several policies, price changes, and other factors has affected the production of liquid biofuels, and unfortunately not all aspects could be covered

given the scope of the thesis. The research question: "*What are the reasons behind the sharp increase in the production of liquid biofuels seen after 2005?"* has been answered. However, again due to scope-limitations, the question was not answered fully, which is where future research comes in as outlined in section 6.3. Regardless, it is an interesting and relevant topic. Additionally, although biofuels policy was the topic of the thesis, it can still be useful in other areas of research as policy implications are relevant across all sectors.

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