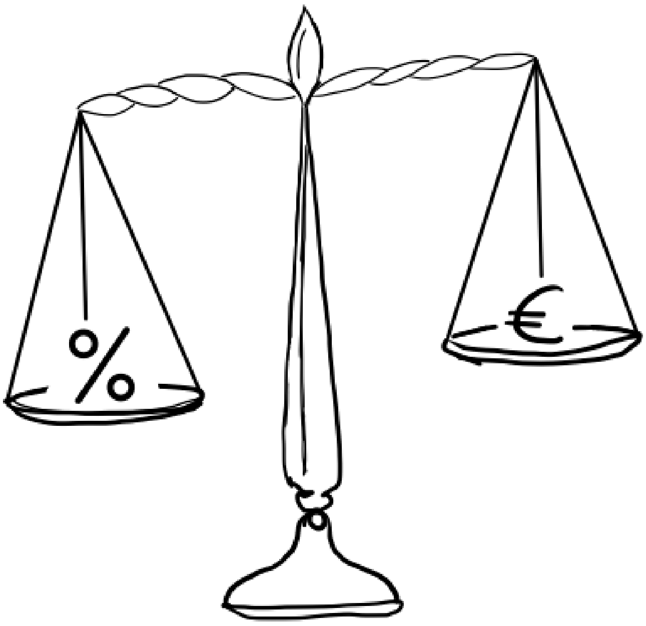

Mandates and Penalties: The Impact of Policy Implementation on Biofuel Markets

A Comparative Study on Road and Aviation Transport Fuel Prices in Different EU Countries

Master's thesis in Industrial Ecology

SUNNA FORSLUND

DEPARTMENT OF MECHANICS AND MARITIME SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Visualisation of a scale weighing the impact of penalties for non-compliance against biofuel blending mandates.

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Abstract

To achieve the European Union's goal of climate neutrality by 2050, substantial reductions in greenhouse gas (GHG) emissions are required in the domestic transport sector. One way to support this transition is to decrease the use of fossil fuels by increasing the share of biofuels through blending mandates. All EU-27 Member States have implemented national biofuel blending mandates for road transport fuels, while by 2022, only France and Sweden had introduced such mandates for aviation fuel.

This thesis aimed to map penalties for non-compliance with biofuel blending mandates in the road transport and aviation sectors across EU Member States, and to assess their impact on fuel prices. Based on penalty levels, the study estimated the corresponding effects on biofuel prices to investigate how much fuel suppliers are willing to pay to avoid penalties. Furthermore, a comparison between theoretical fuel prices and actual consumer prices has been conducted. Lastly, this thesis examined whether there is a correlation between penalty levels and the degree of compliance with biofuel blending mandates.

The findings highlighted how penalty levels vary in both size and formation across EU Member States. Most countries apply per-unit penalties in the road transport sector, while others impose fines of judicial measures, and for a few could no penalties at all be found. Biofuel mandate threshold prices (i.e., what fuel suppliers would be willing to pay for biofuels to avoid the penalty) were calculated and connections to the penalty level were identified. This was also reflected in the consumer prices of blended fuel, as higher biofuel mandate threshold prices resulted in higher theoretical consumer prices. These were generally higher than actual prices, suggesting that in most countries, fuel suppliers were not forced to pay the full biofuel mandate threshold price.

Lastly, this thesis highlighted how biofuel blending mandates and penalties are implemented in different formulations and levels across EU Member States. However, penalty levels do not necessarily correspond directly to the degree of fulfilment of the mandate. In general, the implementation of biofuels is more widespread in the road transport sector than in aviation, which could be the result of more developed markets for road transport biofuels.

Keywords: biofuel policy, GHG emission reduction, transport sector, penalty, blending obligation.

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Sunna Forslund, Gothenburg, May 2025

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis, listed alphabetically:

CO_2-eq	Carbon Dioxide Equivalent
EU	European Union
FAME	Fatty Acid Methyl Esters
FQD	Fuel Quality Directive
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HEFA	Hydro-processed Esters and Fatty Acids
HVO	Hydrotreated Vegetable Oil
ILUC	Indirect Land-Use Change
RED	Renewable Energy Directive
RFNBOs	Renewable Fuels of Non-Biological Origin
RQ	Research Question
SAF	Sustainable Aviation Fuels
Toe	Tonne Oil Equivalent
UCO	Used Cooking Oil
US	United States

Glossary

The following is a glossary of definitions that have been used throughout this thesis, listed in alphabetical order.

Advanced biofuels	Biofuels produced from the feedstocks listed in Part A of Annex IX in the Renewable Energy Directive (RED).
Biofuel mandate threshold price	As defined in this thesis, it corresponds to the maximum price that a buyer theoretically would be willing to pay per litre of biofuel to comply with the biofuel blending mandate. In this study, taxes are not included in the price.
Biofuels	Liquid fuels derived from a non-fossil feedstock.
Biodiesel	Biofuel that can be blended into fossil diesel to reduce its greenhouse gas (GHG) emissions. In this report, refers to fatty acid methyl esters (FAME) and hydrotreated vegetable oil (HVO).
Biogenic carbon	Carbon from the atmosphere sequestrated during biomass growth, that are released back due to combustion of biofuels.
Blended fuel threshold price	As defined in this thesis, it corresponds to the calculated consumer price of a fuel blend based on the fuel shares reported into Eurostat.
CO_2-equivalent	A metric measure for comparing emissions of different GHGs based on their global warming potential, which is converted to a basis of carbon dioxide emissions.
Consumer price	As defined in this thesis, it corresponds to what the consumer pays for a fuel blend at the pump station. In this study, taxes are not included in the consumer price.
Double counting	Legislative mechanism to promote biofuels of certain types, where specified fuels are allowed to be "double counted" towards a mandate. This is also what is considered when a Member State evaluates their progress towards RED.
Feedstock	Raw material used as input in a chemical process to be refined into a desired product.
Fossil fuels	Liquid fuels derived from crude oil. In this report it is exclusively considered as the liquid fuel derived from crude oil, and specifically used to collectively refer to petrol, diesel, and jet kerosene.

Continued on next page

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General penalty	As defined in this thesis, it corresponds to a penalty that is not specified per fossil fuel type. Can be given on either energy, volume, or GHG emission reduction basis.
Lifecycle emissions	Total emissions emitted from a product during its lifetime. Includes emissions accumulated during production, operation, and disposal.
Mandate	As defined in this thesis, a mandate is a law requiring fuel suppliers to blend in a certain share of biofuel into the fuel.
Market-pull policy	A policy designed for promoting a product to help establish a market.
Maximum price	As defined in this thesis, it corresponds to the highest price a buyer is theoretically willing to pay. In this study, taxes are not included in the maximum price.
Non-fossil	Not derived from fossil feedstock.
Penalty	As defined in this thesis, a penalty is a fine which has to be paid if the fuel supplier does not comply with national biofuel blending mandates.
Price	The price a buyer is willing to pay for a product, excluding taxes.
Renewable fuels of non-biological origin (RFNBO)	Liquid or gaseous renewable fuels that are not derived from biomass. In this thesis RFNBOs are lumped together with biofuels under the term biofuels.
Sustainable Aviation Fuel (SAF)	Liquid fuel derived from a non-fossil feedstock to replace fossil-based, conventional aviation fuel.
Transport sector	Includes domestic road and aviation transport, and excludes shipping and rail.

Contents

List of Figures

List of Tables

1

Introduction

To meet the goals in the Paris agreement, the European Green Deal was established as a compass to guide the European Union (EU) on how to reach a reduction in greenhouse gas (GHG) emissions of 55% in 2030 and achieve climate neutrality by 2050 [1]. GHG emissions from the domestic transport sector corresponded to 23.8% of the total EU emissions in 2022, making it the second largest source of emissions within the EU [2]. Such a share accounts for domestic road transport, aviation, railways and shipping, with road transport contributing to the highest share of 73% of emissions [3]. Domestic aviation accounts for almost 14% of the transport sector's emissions, making it the second largest emitter [4]. When including international aviation and shipping, the aggregated emissions from the transport sector correspond to 30.9% of all emissions from the EU [2].

In all sectors of the EU, GHG emissions have declined compared to 1990 levels [3]. In 2023, GHG emissions were reduced by 8.3% which has been described as the largest reduction share in decades and it resulted in a total emission reduction of 37% compared to 1990 levels. During the same period, gross domestic product (GDP) increased by 68%, highlighting the ongoing decoupling of economic growth and emissions [3]. The substantial emission reduction registered in 2023 is closely related to an accelerated transition to renewable energy sources. Despite great efforts, not all sectors have been equally successful in achieving GHG emission reduction, as experienced in the transport sector. As highlighted in the Climate Action Progress Report, the domestic EU transport sector barely registers any reduction in GHG emissions since 2005, despite advances in road electrification and improved road freight transport emission standards [3]. Between 2022 and 2023, emissions decreased by 0.8% in this sector. This slow reduction underscores how the transport sector poses a significant challenge in achieving the EU's emission reduction target for 2030. Although the European Commission expects large emission reductions in the transport sector in the coming years, Member States' own predictions have so far demonstrated limited progress and most have fallen well below the set targets [3].

Although de Oliveira Laurin et al. [5] identify electrification to be a clear long-term path to road transport decarbonisation, there is still a need to understand how the transition will unfold in the short to medium term, but also when applied to hard-to-abate sectors like aviation [3]. Consequently, an approach to mitigate emissions from the transport sector is to use alternative fuels as a substitute for fossil fuels [6]. The European Parliament and the Council recognise seven types of alternative fuels: biofuels, electricity, hydrogen, natural gas in gaseous form, liquefied natural gas, liquefied petroleum gas, and synthetic and paraffinic fuels. Of these, biofuels are currently the most widely used type of alternative fuel in the transport sector in the EU [6]. If produced sustainably, without causing indirect land-use change (ILUC), biofuels can contribute to considerable reductions in carbon dioxide emissions in all modes of transport [6]. The two EU directives, the Fuel Quality Directive (FQD) and the Renewable Energy Directive (RED), aim to increase renewable energy consumption in the EU transport sector by biofuel blending [7, 8]. This can be done by introducing biofuel blending mandates. These mandates are imposed on a national level to encourage the blending of biofuels in fuels for road transport, on an energy, a volume, or a GHG emission reduction basis [9].

The fuel market in the EU road transport sector was dominated by fossil fuels in 2022, accounting for 93.4% of the total fuel share [10]. Of the remaining share, biofuels contributed with 6.6% and electricity to less than 0.1%. The share of fossil fuels consists primarily of diesel and petrol, while among biofuels, the most common types are bioethanol and biodiesels such as fatty acid methyl esters (FAME) or hydrotreated vegetable oil (HVO) [10]. The fuel shares are illustrated in Figure 1.1.

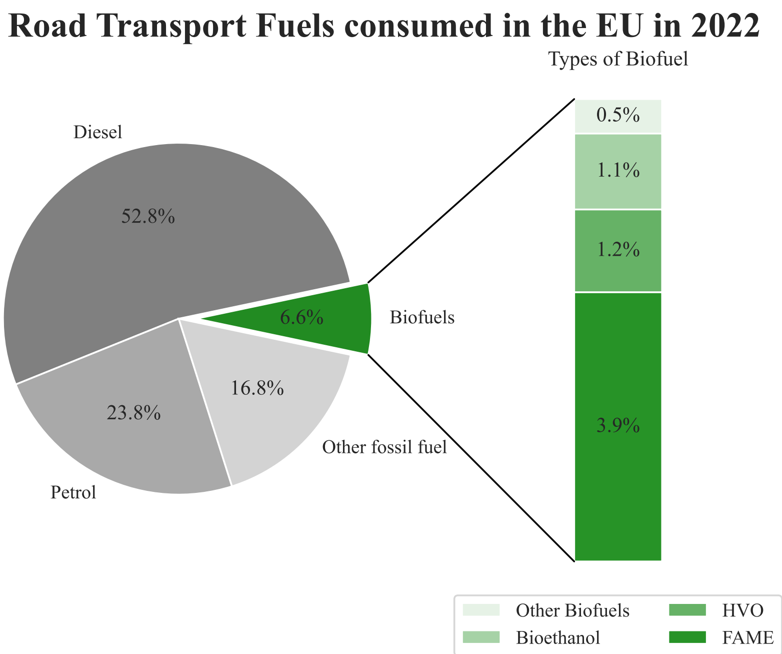


Figure 1.1: Fuel supply shares in the EU's domestic road transport sector in 2022. Data retrieved from Vourliotakis and Platsakis [10].

During 2021, global energy markets began to tighten in the aftermath of the pandemic [11]. Rapid economic rebound and weather conditions, in combination with delayed maintenance work and pre-planned downsizing of oil and gas companies, resulted in rising energy prices. The energy crisis deepened when Russia invaded Ukraine in 2022 and energy prices skyrocketed. In response, the EU imposed sanctions on Russia and began phasing out Russian gas [11]. Global oil prices soared when countries in Europe, Asia, and the US stopped buying Russian oil, and the sharp increase in prices resulted in high inflation and slowed economic growth [11].

To address the energy crisis, the European Commission implemented the REPowerEU Regulation with the goal of phasing out and reducing the European dependence on imports of Russian fossil fuels [12]. Such a plan accounts for diversifying energy supplies, participating in various energy-saving initiatives, and increasing the production of clean energy. The increased production of renewable energy connects the REPowerEU Regulation to RED, making both initiatives interact to support green energy consumption and production in the EU [12].

In 2022, some countries relaxed or abolished their biofuel blending mandates as a way to deal with the increase in fuel prices [13]. In March, Croatia lowered the penalty for non-compliance with the blending mandate. Czechia followed and removed their biofuel blending mandate in March as well. In April, Finland reduced the biofuel blending mandate to 12% from 19.5%. Latvia suspended national mandates in July, making it voluntary to blend in biofuels. In August, the Polish government proposed a relaxation of the mandate. However, the proposal was withdrawn in September and the biofuel blending mandate was not changed [13]. The Swedish government froze the annual increase of their GHG emission reduction mandate for 2023 [14].

1.1 Motivation and Research Aim

This thesis aims to contribute to a deeper understanding of how the implementation of biofuel blending mandates affects the competitiveness and use of biofuels. This is based on the research gaps identified in the following studies.

The European Commission's report on the achievements of the 2020 renewable energy targets [15] identifies biofuel blending mandates as one of the main support schemes to increase the share of renewable energy in the transport sector. The report acknowledges that the design of implemented mandates varies between countries but does not investigate how these design differences may correlate with the resulting share of renewable energy in the transport sector or assess the advantages of different designs. This gap can also be identified in the study by Ebadian et al. [16], which investigates the effectiveness of biofuel policies in a handful of selected countries around the world between 2006 and 2017. The authors describe how biofuel blending mandates are an example of a market-pull policy (i.e., a policy designed to increase the demand of a certain product to help establish a market) aimed at increasing the competitiveness of biofuels against fossil fuels. Generally, a market-pull policy benefits technologies that are more mature, such as ethanol and biodiesels. Furthermore, Ebadian et al. [16] identify how the main drivers for implementing biofuel policies in EU Member States are climate change mitigation and decarbonisation of the transport sector. However, only five EU Member States (Austria, Denmark, Germany, the Netherlands, and Sweden) were included in the study and there was no further analysis of how different types of biofuel blending mandates affected the use of biofuels. Lundberg et al. [9], on the other hand, investigate the development of national blending mandates in the road transportation sector between 2009 and 2020 in various EU Member States. The authors examine how biofuel blending mandates impact biofuel production and usage and how fuel prices and emission reduction are affected. This results in insights such as the importance of biofuel blending mandates as a driver for increased biofuel production and consumption, which results in a reduction in emissions from the transport sector. However, the study only briefly mentions penalties for non-compliance with mandates, but does not further investigate any potential effect of penalties on actual fulfilment of blending mandates.

According to the research gap described above, the aim of this thesis is to map penalties for blending mandates of biofuels in road and aviation sectors across relevant EU Member States and investigate their impact on fuel prices. Consequently, the study will identify the role of penalties in the biofuel market. The findings will contribute to the understanding of how penalties affect fuel markets, which is important for future implementations of blending mandates and penalties.

The research questions (RQs) that will be analysed are presented below:

- RQ1: What are the penalties for non-compliance with biofuel blending mandates implemented in various EU Member States and sectors?
- RQ2: What is the maximum price an actor responsible for fulfilling a blending mandate would be willing to pay for biofuel to avoid a given penalty, and how does this impact the price of blended fuel?
- RQ3: How do actual consumer prices on fuels in relevant EU Member States compare to the maximum consumer prices calculated for blended fuel, based on national penalty levels?
- RQ4: How do specific penalties contribute to biofuel usage and the fulfilment of blending mandates in different Member States and sectors?

1.2 Scope and Delimitations

To narrow down the aim of the report, some limitations are applied:

- This project will focus on national biofuel blending mandates.
- The focus will be on the road transport and aviation sectors. Due to time constraints, the maritime sector will not be considered in this project.
- The temporal focus is on the year 2022, due to data availability.
- Geographical boundaries are set to the EU-27 Member States.
- Taxes will not be included in the price analyses, to enable comparison between EU Member States.

2
Background

This chapter presents an in-depth description of biofuels as well as relevant directives and regulations that affect the results of this thesis.

2.1 Biofuels and Sustainability

Following the definition in RED, biofuels are described as liquid transport fuels derived from biomass feedstocks [8], and are commonly divided into three categories based on the type of feedstock [17]. First generation biofuels refer to conventional biofuels produced from well established technologies, with feedstocks of food and feed crops, such as corn or palm oil. However, since these feedstocks can compete with food, the food-versus-fuel debate has raised concerns about the risk of increasing food prices during food shortages. Second generation biofuels are defined as utilising feedstocks from non-edible energy crops, as wastes or straw. The production of this type of fuel is slightly limited, as it is more complex and the conversion technologies are less mature. Third generation biofuels are produced from certain types of algae, sometimes also including other innovative but not yet commercialised biofuels [17].

When considering the GHG reduction potential from biofuels, it is important to consider the feedstock, as it differs depending on the type of biofuel [10]. The GHG intensity of feedstocks directly affects the emission reduction potential of biofuels. Biofuels with higher GHG intensity feedstocks will only have marginally lower lifecycle GHG emissions than their fossil counterpart, making substitution less substantial [10]. An example of a biofuel with a higher GHG intensity is biodiesel produced from oil crops, especially when considering ILUC, which refers to emissions from the expansion of cropland to produce displaced agricultural products. However, when considering feedstocks such as waste oil for HVO production, the GHG intensity is significantly lower (especially when considering ILUC), resulting in a larger emission reduction potential [10].

2.1.1 Biofuels in Road Transport

In this report, three biofuels are considered for blending in road transport: FAME and HVO in diesel and ethanol in petrol. FAME is commonly used as a blending component in fossil diesel fuel to increase renewable content [18]. Current EU diesel standards allow for up to 7 vol% of FAME without any modification. The fuel is produced through a transesterification process in which fatty acids react with methanol under the activation of a catalyst, replacing an organic glycerol group on the fatty acid with the alcohol group from methanol. This results in the main product, a fatty acid methyl ester (giving the component its name), and glycerol as a byproduct [18]. FAME is often produced from rapeseed, used cooking oil, or biowaste [10].

HVO is chemically equivalent to fossil diesel and can be used directly in diesel engines, without the need for modification or blending [19]. The fuel is free of sulphur and aromatics and has a high cetane number. In the context of aviation, the term hydroprocessed esters and fatty acids (HEFA) is commonly used, yet in this thesis it will be considered as HVO. Feedstocks for producing HVO consists of various vegetable oils and fats containing triglycerides and fatty acids, animal fats, and tall oil. One of the main challenges for scaling up HVO production is feedstock availability [19].

Ethanol can be blended into petrol to reduce carbon dioxide emissions from the fuel [20]. From a chemical perspective, synthetic ethanol and biobased ethanol are identical on a molecular level, enabling a direct blending in the currently used fuel. Bioethanol is produced through the fermentation of sugar solutions from sugar and starch rich crops, mainly consisting of corn, wheat, or sugar cane [10, 20].

2.1.2 Biofuels in Aviation

Conventional aviation fuels are derived from fossil sources, with kerosene-based fuels being the most widely used for transport and passenger flights [21]. One pathway to lower the sector's carbon emissions is to increase the uptake of SAF. SAF has similar properties compared to fossil-based aviation fuel, enabling direct blending and use without modifications in engines and related equipment [21]. The EU's definition of SAF includes recycled carbon aviation fuels, synthetic aviation fuels, and aviation biofuels [22]. Recycled carbon fuels refer to gaseous and liquid fuels derived from non-renewable waste streams, or produced from exhaust or waste processing gas from non-renewable origin, unintentionally generated as a byproduct [8]. Synthetic fuels are produced from renewable feedstock of non-biological origin, while biofuels are derived from feedstocks listed in RED Annex IX Part B (used cooking oil (UCO) and animal fats) [8, 22].

The ReFuelEU Aviation Regulation, which will be described in more detail in Section 2.2.4, aims to stimulate innovation and increase investments in SAF throughout the supply chain, leading to expanded production and uptake of fuel to reduce prices [4]. In 2020, SAF supplied less than 0.05% of total aviation fuel demand in the EU. Production is emerging and set to expand, but is currently limited by production capacity. This affects prices, as SAF can be 1.5-6 times more expensive than conventional fossil aviation fuel [4]. Another factor influencing the SAF price is fluctuating feedstock prices. Main SAF feedstocks are expected to be UCO, sustainable biomass, waste oils, and animal fats [4].

2.2 Policy landscape

Replacement of fossil fuels with biofuels has a significant potential to reduce GHG emissions, making it a key instrument to achieve the targets stated in FQD and RED [10].

2.2.1 Fuel Quality Directive

Focusing on the quality of fuels consumed by the road transport sector in the EU, the FQD was introduced in 1998 and aimed to impose strict requirements to protect the environment and human health [7]. This was done by targeting the reduction of emissions from GHGs and air pollutants, while ensuring fuel compatibility with current engine and exhaust treatment technologies [7, 23]. The directive applies to diesel, petrol, gas oil, and biofuels, establishing minimum quality requirements to reduce air pollution with respect to particulate matter, metallic emissions, and sulphur oxides, among other things. To comply with the technical requirements, a maximum volume-based blending of 10% ethanol in petrol and 7% FAME in diesel was established. Furthermore, since the directive addressed GHG emissions, a 6% reduction in GHG intensity in 2020 in fuels for road transport was required [23]. The FQD guidelines were amended in the second revision of RED, which entered into force in 2023, and the GHG intensity reduction target was moved to RED instead. In accordance with Article 7a of FQD, EU Member States were required to collect and report data on the quality and volume of diesel and petrol fuels sold in their territories for the years 2022 and 2023, to ensure consistency and compliance with the directive [23].

2.2.2 Renewable Energy Directive

RED was introduced in 2009 and is a legal framework to support cooperation between Member States with respect to the implementation of fossil-free energy in all sectors of the EU economy [24]. When RED was implemented, a target of 10% renewable energy in 2020 was established for the transport sector [9]. This was updated in the first RED revision that entered into force in 2018, referred to as RED II, to target 14% renewable energy in the transport sector in 2030 [8, 24]. Following the introduction of the Fit for 55 package [25] in 2021, RED was revised again in 2023, referred to as RED III [9, 24]. The directive presented two possible pathways for the Member States to choose between, in terms of targets for the transport sector for 2030: (i) a binding target of 14.5% reduction of GHG emission intensity; or (ii) a binding share of 29% renewables in the final energy consumption [26]. Furthermore, RED III includes a combined sub-target share for advanced biofuels and renewable fuels of non-biological origin (RFNBOs) of 5.5% to 2030. This also includes a minimum requirement that at least 1% of the renewable energy supplied to the transport sector must come from RFNBOs [27].

The target established in RED I of 10% renewable energy share in the transport sector in 2020 was collectively reached by the EU Member States, resulting in a total of 10.2% renewable energy [15]. However, this was calculated using double counting (i.e., tools to incentivise the use of certain fuels or energy carriers from renewable sources by increasing their contribution to the renewable energy targets [8]) as stated in the RED methodology. Without double counting, the actual share of renewable energy in the transport sector was 7.5%, resulting in a fossil share of 92.5% [13]. Looking closer at the Member States, 12 of the EU-27 exceeded the 10% target when calculating with double counting [15]. Sweden had the highest share of renewable energy with 31.9%, followed by Finland (13.4%). The lowest shares in 2020 could be found in Greece and Lithuania (around 5%) [15]. In 2022, Sweden and Finland were still the countries with the highest share of renewables in the transport sector, while the lowest share of 2.4% could be found in Hungary [28].

2.2.3 Biofuel Blending Mandates in the EU

To reach the targets stated in RED, all EU Member States had implemented some sort of blending mandate for biofuels in 2020 [9]. However, mandate requirements vary between countries in the EU. Most Member States have declared a mandate based on the share of biofuels in either energy content or volume, while three countries (Denmark, Germany, and Sweden) have GHG emission reduction mandates, which determine the blending of biofuels based on the total reduction of GHG emissions from the fuel blend [9]. The design of national biofuel blending mandates varies between Member States, since some have implemented their mandate as an overall share of biofuels, as specific biofuel blending mandates in the petrol and diesel fractions, or have implemented both an overall share and specific mandates for petrol and diesel [9, 13]. In the cases of an overall biofuel blending mandate, it means fuel suppliers could choose to blend in either a bit of biofuel in both petrol and diesel blends, or to only blend in bioethanol or biodiesel and still fulfil the mandate. A list of the mandates implemented by the Member States is attached in Appendix C. The regulations for ensuring compliance with blending mandates vary between countries; however, most countries have established some form of penalty for fuel distributors that do not meet the required blending targets [9]. The relevant penalties are tabulated in Appendix C.

2.2.4 ReFuelEU Aviation Regulation

The ReFuelEU Aviation Regulation is part of the Fit for 55 package and is a complement to RED which sets general rules regarding renewable energy in the transport sector [22]. The REFuelEU framework consists of aviation-specific measures to lower the sector's carbon emissions and to increase the share sustainable aviation fuels (SAF) available at EU airports by imposing blending targets. The Regulation requires a minimum share of 2% SAF in EU airports from 2025, increasing to 6% in 2030, and then continuing to increase every fifth year to reach a 70% share of SAF in 2050. This calls for a significant increase in the production, supply, and adoption of SAF. To comply with the Regulation, penalties on aircraft operators and aviation fuel suppliers should be imposed in the case of non-compliance with blending obligations. The penalties should be proportionate, deterrent, and effective, as stated in the Regulation [22]. Several aspects should be taken into account by authorities when deciding on the size of the penalty, as it ought to be proportionate to the environmental harm caused and the market impacts on not complying with the blending mandate. The price evolution of SAF and conventional aviation fuel and the extent of non-compliance should also be considered [22]. In 2021, Sweden became the first EU country to implement a national SAF blending mandate, followed by France in 2022 [29]. Several other countries, such as Finland, Germany, and the Netherlands, have begun developing similar regulatory measures. Sweden has a GHG emission reduction mandate of 1.7% per calendar year in 2022, similar in implementation to the mandate in the road transport sector with an annual increase of the mandate. France, on the other hand, has a volumetric requirement of 1% SAF in the total fuel blend [29].

2.2.5 Greenhouse Gas Reduction Mandate in Sweden

The Swedish government implemented a mandate on reducing GHG emissions in the domestic transport sector in 2018 to encourage the blending of biofuels in road transport fuels (diesel and petrol) [30]. In 2021, a GHG emission reduction mandate was implemented on aviation fuel as well. Sweden has a national goal of reducing the GHG emissions from domestic transport with 70% by 2030 compared to 2010, and the reduction mandate is intended to contribute to this [31]. To reduce the climate impact, the emission reduction percentages were supposed to increase every calendar year until 2030. However, when Russia invaded Ukraine in 2022 and fuel prices soared, the annual increase in the GHG emission reduction mandate was paused for 2023 [14]. Furthermore, after a government proposal in 2023, the reduction mandates for diesel and petrol were reduced for the time period 2024-2026 and abolished for the years 2027-2030. An argument for lowering the mandate was to address fuel prices [32]. The reduction mandates in Sweden between 2018 and 2030 for diesel, petrol, and aviation fuel can be seen in Table 2.1.

Table 2.1: Greenhouse gas emission reduction mandates in Sweden for diesel, petrol, and aviation fuel in percent during the time span 2018-2030. The numbers in brackets for diesel and petrol from 2024 to 2030 indicates the intended increase in reduction mandates, previous to the governmental proposal in 2023. Data retrieved from the Swedish Energy Agency [30].

Year	Diesel (%)	Petrol (%)	Aviation fuel (%)
2018	19.3	2.6	–
2019	20.0	2.6	–
2020	21.0	4.2	–
2021	26.0	6.0	0.8
2022	30.5	7.8	1.7
2023	30.5	7.8	2.6
2024	6.0 (40.0)	6.0 (12.5)	3.5
2025	6.0 (45.0)	6.0 (15.5)	4.5
2026	6.0 (50.0)	6.0 (19.0)	7.2
2027	– (54.0)	– (22.0)	10.8
2028	– (58.0)	– (24.0)	15.3
2029	– (62.0)	– (26.0)	20.7
2030	– (66.0)	– (28.0)	27.0

In August 2024, the government announced a planned increase in the reduction mandates for petrol and diesel, to reach the EU's climate targets [33]. Combined with lowered taxes on transport fuel to counteract price developments, this is predicted to result in an emission reduction of around two million tonnes CO_2-eq until 2030 [33].

To ensure compliance with the reduction mandate, a penalty for not fulfilling the mandate per calendar year has been instated [34]. The fee is given in SEK per remaining GHG emissions in kg carbon dioxide equivalents (CO_2-eq) required to fulfil the mandate. The penalties for exceeding the GHG emission reduction mandates in Sweden in 2022 are [35]:

- 4 SEK per kg CO_2-eq for diesel
- 5 SEK per kg CO_2-eq for petrol
- 6 SEK per kg CO_2-eq for aviation fuel

During the period 2018 to 2022, no infringements of the GHG emission reduction mandate for petrol was made by fuel suppliers [36]. However, for diesel, infringements were reported for 2018-2021, with a majority of cases reported during 2019 and 2020. Some fuel suppliers fulfilled their reduction mandate by purchasing surplus emission reduction certificates from other actors. This market approach is applied to both petrol, diesel, and aviation fuel, but the largest market share of emission reduction trading goes to fulfilling the diesel mandate. Looking at the SAF blending mandate, the reported offences increased from the calendar year 2021 to 2022. As described above, the GHG emission reduction mandate for aviation fuel in 2022 were 1.7%, but only a reduction of 1.22% was reached. Of the five fuel supplying actors responsible for following the reduction mandate, only two succeeded while the other three had to pay fines of 69 million SEK, in total [36].

3

Method

This chapter presents the method specifically developed and applied in this study, including performed equations and assumptions. The data used in the calculations are included in Appendix A.

3.1 Main Equations

The aim of this thesis is to map penalties for non-compliance with biofuel blending mandates in the road and aviation transport sectors within different EU countries and to investigate the impact of these penalties on fuel prices. The equations presented in the following contribute to the achievement of that aim.

Included parameters, their denominations, and units in the equations:

- Emission intensity of biofuel, E_B [kg CO_2-eq/L fuel]
- Emission intensity of fossil fuel, E_F [kg CO_2-eq/L fuel]
- National set penalty for non-compliance, P [€/kg CO_2-eq]
- Overall biofuel blending mandate, M_O [%]
- Price of biofuel, I_B [€/L fuel]
- Price of fossil fuel, I_F [€/L fuel]
- Specific biofuel blending mandate in diesel, M_D [%]
- Specific biofuel blending mandate in petrol, M_P [%]
- Specific biofuel blending mandate in aviation fuel, M_{SAF} [%]
- Share of biodiesel in blended diesel, $X_{B,D}$ [%]
- Share of biofuel in blended fuel, X_B [%]
- Share of ethanol in blended petrol, $X_{B,P}$ [%]
- Share of SAF in blended aviation fuel, X_{SAF} [%]
- Volumetric energy density of fossil fuel, D_F [MJ/L]

The variables added in this study, their denominations and units are described as:

- Biofuel mandate threshold price, $I_{B,MAX}$ [€/L fuel]
- Consumer price of a blended fuel, I_{MARKET} [€/L fuel]
- Fulfilment of national biofuel blending mandates, F [%]

3.1.1 Penalty Levels

National penalties for non-compliance with biofuel blending mandates can be imposed at various levels, with the three main levels being: energy-based, volume-based, or GHG emission reduction-based. Three of the assessed countries, Austria, Poland, and Sweden, had declared separate penalties for petrol and diesel. Other countries had instead chosen a general penalty (i.e., a penalty not specified per type of fossil fuel). To allow a comparison of the penalties and further address the scope of RQ1, they were transformed into a common unit (€/MWh).

If the penalty was energy-based, it was multiplied by the conversion factor MJ/MWh, as stated in Appendix A, to obtain a penalty in €/MWh. If the penalty was given on a volume basis, it was divided with the volumetric energy density in MJ/L of the fossil fuel, obtaining an energy-based penalty which could be converted into the correct units as described above. As some of the general penalties were given on a volume basis, they were instead divided by the mean value of the volumetric energy density for petrol and diesel. This resulted in an average general penalty on an energy basis, that could be used in the analysis. For penalties given on a GHG emission reduction base, they were multiplied by the emission factor in kg CO_2/MJ for the fuel in question, gaining a penalty on an energy basis to be converted as described above. In the case of Germany, that has a general penalty for petrol and diesel applied on a GHG emission reduction mandate, the penalty was multiplied by the average emission factor for petrol and diesel. This resulted in an aggregated penalty on an energy basis that could be converted into €/MWh as described above.

3.1.2 Biofuel Mandate Threshold Price

To find the maximum price per litre of biofuel ($I_{B,MAX}$) that fuel suppliers would theoretically be willing to pay to fulfil a GHG emissions reduction mandate, Equations (B.1b), (3.2) and (B.3) are combined. In this thesis, the price is calculated according to Equation (3.1a), which is referred to as the biofuel mandate threshold price. If the penalty is given on an energy or volume basis, Equation 3.1b or Equation 3.1c is used, respectively.

$$I_{\mathrm{B,MAX}} = P \cdot (E_F - E_B) + I_F \tag{3.1a}$$

$$I_{\mathrm{B,MAX}} = P \cdot D_F + I_F \tag{3.1b}$$

$$I_{\mathrm{B,MAX}} = P + I_F \tag{3.1c}$$

In general, and in response to RQ 2, Equation (3.1a) describes the mathematical connection between the price of biofuels and their emissions. The lower the emissions of the biofuel, the larger is the incentive to pay for it to reach the blending mandate. Equations (3.1b) and (3.1c) describe how the biofuel mandate threshold price is calculated when the penalty given in MJ/L or €/L, respectively.

3.1.2.1 Sensitivity Analysis of Emission Factors

The available biofuels on the market can have significant differences in their emission reduction potential. For example, the GHG intensity for FAME produced from oil crops compared to HVO from waste oil could greatly impact the emission reduction potential when blended into fossil diesel [10]. Respectively, a sensitivity analysis (i.e., evaluating a result based on changes in input data and assumptions [37]) was performed to illustrate how the emission factor of a given biofuel affects the price per litre of fuel. For the purpose of this study, HVO and FAME on the Swedish fuel market were considered. The emission factors, E_B, were increased with 50% and decreased with 50%, in 10 percentage point steps. Expanding the sensitivity analysis to include different fuels further highlights how fuels with lower environmental performance have a lower biofuel mandate threshold price and how the price increases as a response to an improved environmental performance.

3.1.3 Theoretical Consumer Fuel Prices

The total price that consumers have to pay for one litre of fuel for a given blended fuel mix is calculated according to Equation (3.2). The equation describes the price of the blended fuel, given a certain share of biofuel, which varies according to the share of biofuel.

$$I_{\text{MARKET}} = (1 - X_B) \cdot I_F + X_B \cdot I_B \tag{3.2}$$

Equation (3.2) clarifies how the share of biofuel will affect the total price of the blended fuel. For example, if the biofuel share is large and has a high price compared to a lower fossil price, it will increase the total price considerably.

Merging together the results of Equation (3.1a), (3.1b), or (3.1c) and Equation (3.2) allows for calculating the price per litre of blended fuel and thus the maximum theoretical consumer price (i.e., the highest possible price for the blended fuel when fulfilling the blending mandate). The theoretical consumer price, when compared to the actual fuel market price, offers insight into RQ 3. If the theoretical consumer price is significantly higher than the actual fuel market price, it could mean either that the mandate was not met, or the fuel could be subsidised somehow. However, if the actual fuel market price is close to the theoretical consumer price, it means that the fuel suppliers were pushed by market mechanisms to pay higher prices for the fuel feedstock which raises the consumer prices at the pump. This is in connection with the previously calculated biofuel mandate threshold prices for bioethanol, FAME, and HVO. If feedstock prices rise, but still are lower than paying the penalty, it will be economically beneficial for fuel suppliers to pay for the feedstock, thus increasing the actual consumer fuel prices at the pump and nearing the theoretical consumer prices.

3.1.3.1 Sensitivity analysis of Blended Fuel Prices

When calculating the consumer fuel prices, an assumption was required regarding the price of the fossil fuel, as described in more detail in Section 3.3.2. Since no reliable spot market prices for fossil petrol or diesel could be found, the EU average consumer prices for petrol and diesel were used as the price of the fossil component. To assess the robustness of this assumption, a sensitivity analysis was performed on consumer fuel prices to investigate the effect of price variations in the fossil fuel. The price of fossil fuel in Equation (3.2), I_F, was increased with 25% and decreased with 25% in five percentage point steps.

3.1.3.2 Actual Fuel Shares

As earlier mentioned, when an overall biofuel blending mandate is imposed, fuel suppliers face a choice on how to comply with the mandate. Theoretically, they could decide only to mix ethanol in petrol or biodiesel in diesel. However, the share of biofuel would then have to be rather large and therefore result in a high fuel price. As it was considered more probable that fuel suppliers would choose to blend in both bioethanol and biodiesel, the actual shares of biofuels consumed in the Member States were recovered from the Eurostat dataset *Final energy consumption by type of fuel* [38]. In Member States with both an overall biofuel blending mandate and specific mandates for petrol and diesel, fuel suppliers also face a choice on how to meet the mandates, but it is not as free since they still have to comply with the specific mandates for petrol and diesel. To illustrate the fuel suppliers' choice, an error bar was used to project how much the price could potentially increase if fuel suppliers had instead decided to only blend in ethanol or biodiesel to comply with the mandate. To demonstrate how the result will be presented, an example of petrol prices was selected for a schematic illustration in Figure 3.1.

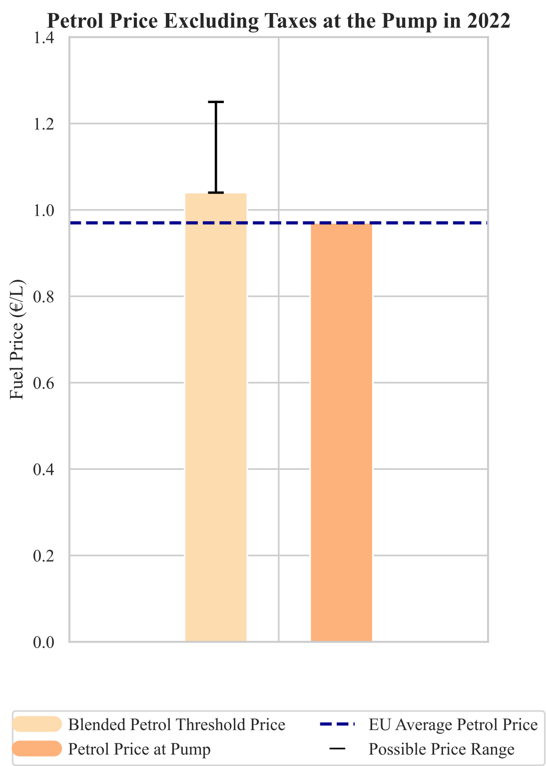


Figure 3.1: Visualisation of how the results in Figure 4.6 are presented.

The blended petrol threshold price in Figure 3.1 corresponds to the calculated consumer price (I_{MARKET}), based on consumed fuel shares as reported to Eurostat [38]. The error bar depicting the possible price range illustrates how the consumer price is affected by the fuel suppliers' choice on how to fulfil the blending mandate. In the example in Figure 3.1, had fuel suppliers decided to meet the mandate by blending more ethanol into the fuel mix, the consumer petrol price could have increased to around €1.3/L. In this example, the actual petrol price level is around €0.98/L, close to the EU average petrol price, as demonstrated by the column to the right in Figure 3.1.

3.2 Fulfilment of Biofuel Blending Mandates

To investigate the degree of fulfilment of biofuel blending mandates in Member States, a comparison of the actual consumed share of biofuels in relation to the national mandate was carried out. Following the RED methodology, for countries with overall energy- or volume-based biofuel blending mandates, total biofuel consumption including double counting was used. This data was retrieved from the Eurostat dataset *Use of renewables for transport - details* [39]. For countries with specific blending mandates for petrol and diesel, no double counting was used because there was no separate reporting to Eurostat. The consumed biofuel shares were retrieved from the Eurostat dataset *Final energy consumption by type of fuel* [38]. A case study on Sweden was performed to assess how the Member State managed to meet their biofuel blending mandates in petrol and diesel during the period 2018-2023. In Sweden, high-blend biofuels are not allowed to be included into the fulfilment of the GHG emission reduction mandate [40]. The shares of consumed fuels reported to Eurostat do not differentiate between high-blended and low-blended fuels, which means that the Swedish degree of mandate fulfilment in reality might be lower.

The fulfilment of an overall biofuel blending mandate was calculated as follows in Equation (3.3a). Equations (3.3b) and (3.3c) further describe the fulfilment of specific mandates for petrol and diesel, as well as specific mandates in combination with an overall mandate, respectively.

$$F = \frac{X_B}{M_O} \tag{3.3a}$$

$$F = \frac{X_{B,P} + X_{B,D}}{M_P + M_D} \tag{3.3b}$$

$$F = \frac{X_{B,P} + X_{B,D} + X_B}{M_P + M_D + M_O} \tag{3.3c}$$

This results in a normalised evaluation of how close the Member States came to fulfilling their blending mandates.

For the aviation sector, a similar method was applied. Data on SAF use in Sweden were extracted from the Swedish Energy Agency [29] and for France from the Eurostat dataset *Final energy consumption in transport by type of fuel* [41] and SHARES [42]. Mandate fulfilment in aviation transport was calculated as follows in Equation (3.4).

$$F = \frac{X_{SAF}}{M_{SAF}} \tag{3.4}$$

3.3 Calculation Assumptions and Input Data

This section presents the key assumptions and input data used in the calculations to obtain results and insights regarding the impact of biofuel blending mandates on fuel markets in the EU.

3.3.1 Biofuel Blending Mandates and Penalties

In this thesis, road transport fuel mixes were considered to contain only three types of biofuel; bioethanol in petrol, and HVO and FAME in diesel. In addition, only nationally decided biofuel blending mandates were studied. Therefore, the 6% GHG emission reduction mandate based on an EU directive was not included in the analysis. The targets for advanced biofuels were not included as well, as the shares reported to Eurostat [38, 39] do not explicitly recount specific shares of fuels, rather than bioethanol and biodiesels. Therefore, it was not possible to identify whether the advanced targets were met or not. This was applied to the Hungarian biofuel blending mandate in diesel, since it was specified for HVO, and therefore excluded from the analysis.

When assessing the aviation sector, only Sweden and France were evaluated, as they had SAF blending mandates implemented for 2022.

National penalties for non-compliance with biofuel blending mandates were retrieved from reports by Koster et al. [13] and the United States Department of Agriculture [43]. A complete list of the extracted penalties, as well as the mandates, can be found in Appendix C. For the purpose of a meaningful penalty comparison, only penalties expressed in monetary terms per unit of volume or energy (such as €/L or €/MJ) were included in the analysis. The ten countries Bulgaria, Denmark, Estonia, Greece, Latvia, Lithuania, Malta, the Netherlands, Romania, and Slovenia were considered to not have per-unit based penalties that be transformed into the common unit €/MWh and were not included in the penalty comparison analysis. Examples of such penalties are a fine of 200,000 BGN in Bulgaria, a fine range of €1200–10,000,000 in Estonia, or as in the Netherlands, where fuel suppliers can be brought to court for an economic misdemeanour [13]. The ten Member States were also excluded from the biofuel mandate threshold price calculations, since the results were based on the penalty level. In the comparison of blended fuel prices, only actual consumer prices for these Member States were analysed.

3.3.2 Prices and Taxes

Market prices for fossil petrol and diesel were assumed to be the EU average prices, since some countries have a very low biofuel content in their blended fuel. Weekly average prices in the EU were obtained from the European Commission's Weekly Oil Bulletin [44], then aggregated into annual average prices. Consequently, the assumed annual EU average price for petrol was €0.97/L and €1.10/L for diesel. The Weekly Oil Bulletin [44] also provided weekly national prices of blended petrol and diesel fuel without taxes for the assessed EU countries. An annual average was aggregated from the stated weekly prices and used for comparison with theoretical blended fuel prices. The average prices per litre biofuels in road transport in the EU were recovered from the Swedish Energy Agency [36]. The price per litre of ethanol is €1.03/L, €1.60/L for FAME, and HVO is the most expensive at €2.07/L. Prices for aviation fuel and SAF were extracted from IATA [45] and assumed to be €0.84/L for fossil jet fuel and €1.75/L for SAF. Since SAF production is on a small scale, aviation fuel is considered to be completely fossil, and the average price of jet fuel in the EU is equal to the fossil price.

Taxes on fuel prices were excluded from the extracted national prices to allow comparison between countries. Since the level of taxes vary between Member States in the EU, comparing prices without taxes provides a clearer understanding of how blending mandates and penalties affect the national fuel markets.

Exchange rates for converting the local currency to euro were extracted from the European Central Bank [46], using the average exchange rate for the year 2022.

3.3.3 Emission factors

When the environmental impact of a blended fuel was calculated for countries with an energy-based or a volume-based biofuel blending mandate, average values of emission factors in the EU were used. This is because these types of mandates do not promote the use of biofuels with lower lifecycle emissions, as a GHG emission reduction mandate does. Therefore, other emission factors were applied in the calculations for Denmark, Germany, and Sweden. Fuel suppliers in these countries are more likely to choose a biofuel with lower lifecycle emissions, while fuel suppliers in other countries prefer a biofuel with a lower price, as it would be the cheapest way to fulfil the blending mandate. For example, the emission factor for ethanol in Sweden is significantly lower than the EU average, which could be because Sweden allows the counting of negative emissions if the ethanol is produced from, e.g., food waste [47]. Ideally, the emission factors for the fuels in Denmark, Germany, and Sweden would be based on the fuels used in that specific country. However, since Sweden's GHG emission reduction mandate is the most extensive, the emission factors of the fuels used in Sweden were also applied to the calculations for Denmark and Germany.

4
Results

This chapter presents the selected results of the method developed and applied in this thesis. To facilitate the understanding of the results, this chapter is divided into four sections:

- Penalty levels
- Biofuel Mandate Threshold Prices
- Comparison of Blended Fuel Prices
- Fulfilment of Biofuel Blending Mandates

4.1 Penalty Levels

National penalties for biofuel mandate non-compliance in road transport vary greatly in size and design between Member States, and are illustrated in Figure 4.1. Of the 27 Member States included in the analysis, 17 countries had penalties on road transport fuels that could be transformed into the common unit €/MWh. Originally, these penalties were given on a volume basis in €/L, on an energy basis (€/MJ), or on a basis of GHG emission reduction (€/kg CO_2-eq). Austria, Poland, and Sweden, have separate penalties for petrol and diesel, while the remaining Member States have a general penalty. Upon a closer look at Austria, Poland, and Sweden, it becomes clear that Austria and Sweden have higher penalties on petrol than on diesel. Contrarily, Poland, despite having stated separate penalties for non-compliance with biofuel blending in petrol and diesel, registered these penalties at the same level. For the case of Austria and Sweden, the higher penalty on petrol could be motivated by a higher incentive for fuel suppliers to meet the petrol blending mandate than the diesel mandate, avoiding paying a higher penalty.

As demonstrated in Figure 4.1, the enforced penalties range between less than €1/MWh in Croatia and up to €25/MWh in Hungary. According to 2022 data, the penalty level averaged around €10/MWh, with Czechia, Finland, Luxembourg, Spain, and Sweden registering penalties within the same range.

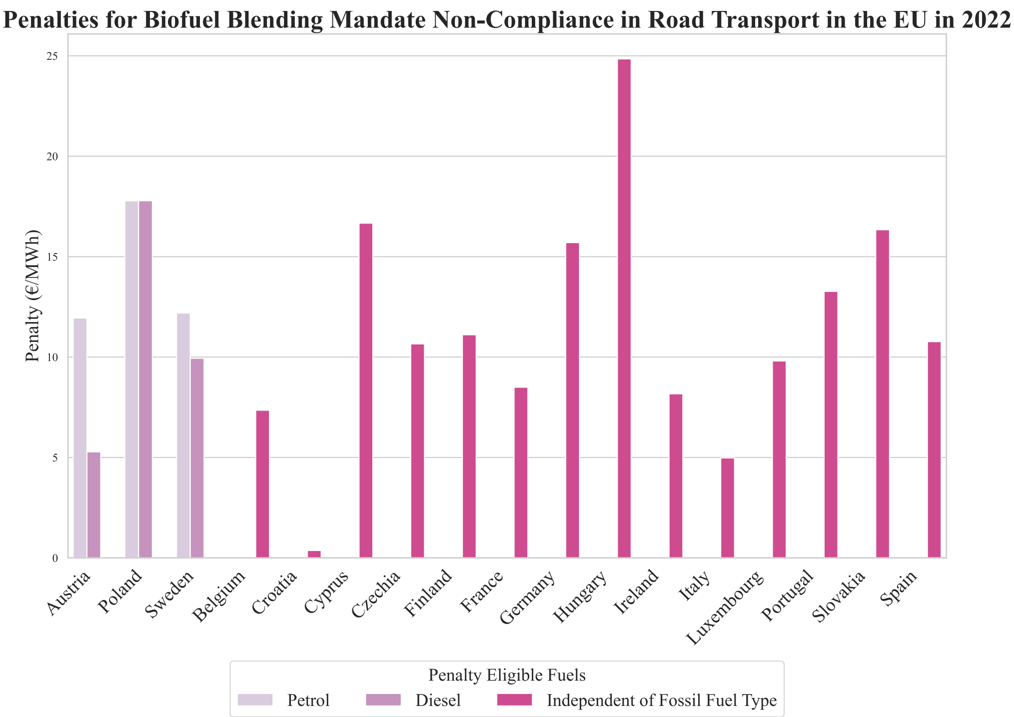


Figure 4.1: Penalties (y-axis) on road transport fuels in EU Member States (x-axis) in 2022. The penalties are either given separately for petrol and diesel fractions, or as a general penalty for overall biofuel blending, in €/MWh. Data retrieved from Koster et al. [13].

Ten countries were excluded from the penalty comparison since their penalty applications were considered not to be comparable with the other 17 Member States, neither on a per-unit basis nor as normalised. These countries and their respective penalties are described in Table 4.1.

Table 4.1: EU Member States without per-unit based penalties for non-compliance with the biofuel blending mandates. Data retrieved from Koster et al. [13].

Country	**Penalty**
Bulgaria	200,000 BGN
Denmark	Fuel suppliers who fail to meet the GHG reduction mandates may be fined and face imposed criminal liability
Estonia	€1200-10,000,000
Greece	€5000-1,500,000
Latvia	-
Lithuania	-
Malta	€100,000
Netherlands	Fuel suppliers who fail to meet the blending mandates may be taken to court for an economic misdemeanour
Romania	RON 70,000-100,000
Slovenia	-

As visualised in Table 4.1, Bulgaria, Estonia, Greece, Malta, and Romania have a penalty given as a fixed amount regardless of the quantity of fuel or energy, ranging in size. Denmark and the Netherlands express non-monetary implications, while no stated penalties could be found in Latvia, Lithuania, and Slovenia. For the Member States with a fine range, it is not clear on what grounds the range is based on. Similarly to Bulgaria and Malta, which have registered set fines, it is not identified whether the penalty is enforced at once in its entirety or if it is applied in accordance with the size of the violation.

Penalties for non-compliance with the SAF blending mandate in aviation fuel are visualised in Figure 4.2. France and Sweden were the only Member States that had penalties enforced during 2022. Similarly as for road transport fuel penalties, they are originally given in different units, with the French penalty in €/L and the Swedish penalty in SEK/kg CO_2-eq. Given the scope of this analysis, the penalties were transcribed into €/MWh to enable comparison.

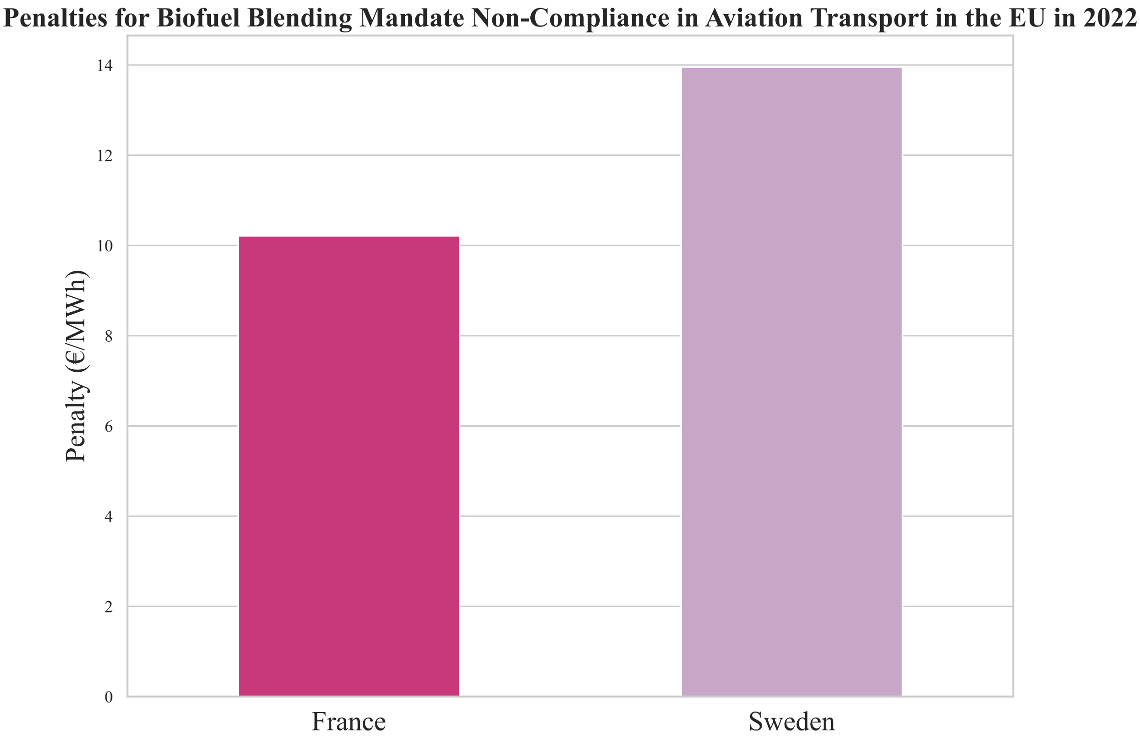


Figure 4.2: Penalties (y-axis) in €/MWh to ensure fulfilment of biofuel blending mandates in aviation transport in France and Sweden (x-axis). Data extracted from Koster et al. [13].

As depicted in Figure 4.2, a higher penalty was registered in Sweden, compared to France. Such a trend is in line with what has been observed in road transport, where the Swedish penalties for petrol and diesel were registered at higher levels than the general French penalty. Furthermore, the penalties for aviation transport fuels are higher in both France and Sweden, compared to their respective penalties for fossil road transport fuels. This could point to an increased motivation for fuel suppliers to comply with the SAF blending mandates, even if the market is not yet stabilised.

4.2 Biofuel Mandate Threshold Price

The biofuel mandate threshold price indicates the maximum price per litre of biofuel a fuel supplier would have to pay when mixing a fuel blend that fulfils a biofuel blending mandate, to avoid the penalty. In case the price per litre of biofuel exceeds that threshold, it would be economically justifiable for the fuel supplier to not blend in biofuels and instead take the penalty. Following the calculations described in Section 3.1.2, the prices for road transport and aviation fuels are illustrated below.

4.2.1 Road Transport Fuels

Figure 4.3 visualises how the biofuel mandate threshold price in the road transport sector varies according to the size of the penalty, where Figure 4.3 a) illustrates the biofuel mandate threshold price for ethanol and Figure 4.3 b) illustrates the biofuel mandate threshold price for HVO and FAME. The horizontal lines in Figure 4.3 a) indicate the average price of ethanol in the EU, while the two lines in Figure 4.3 b) indicate the EU average prices for HVO and FAME.

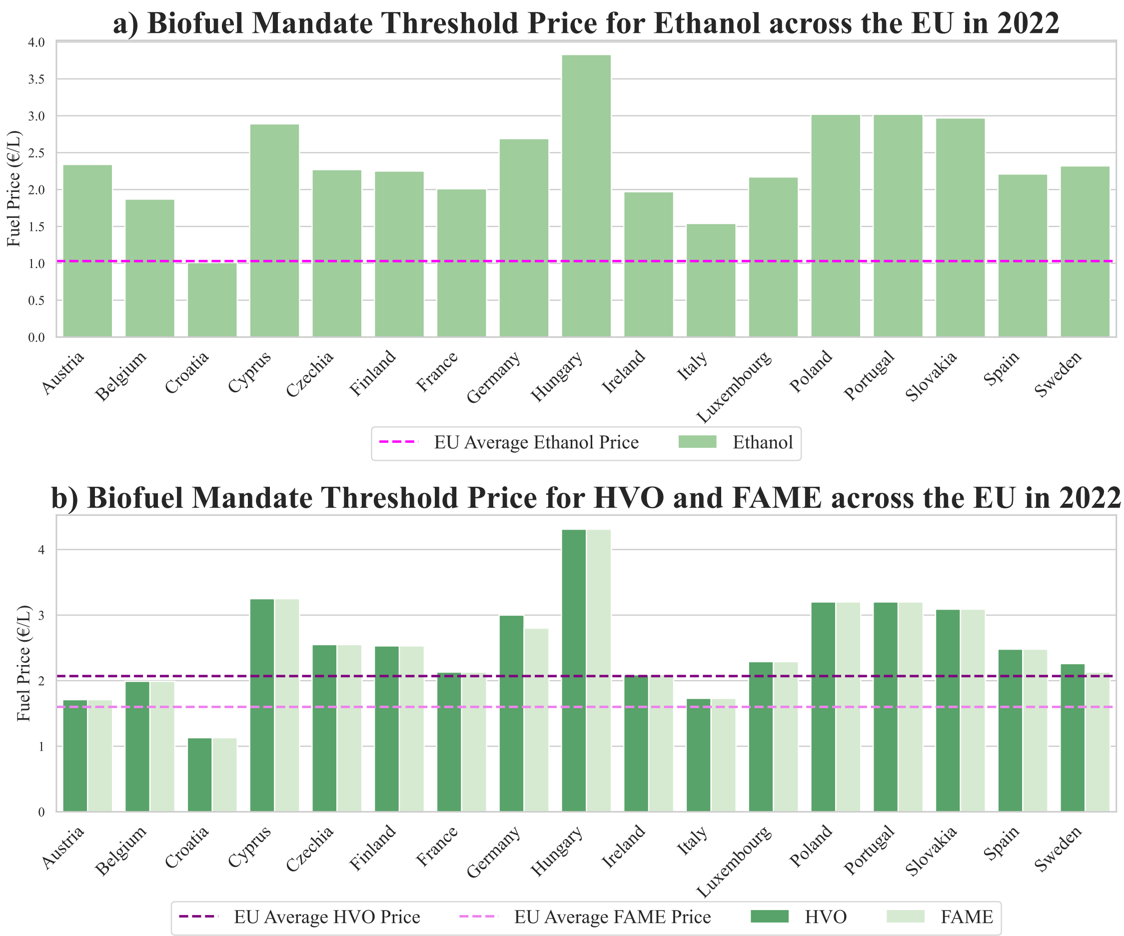


Figure 4.3: Biofuel mandate threshold prices (y-axis) in €/L that fuel suppliers are willing to pay per litre of biofuels used in road transport, varying between EU Member States (x-axis) in 2022. Figure 4.3 a) illustrates the ethanol price and Figure 4.3 b) the HVO and FAME prices.

Figure 4.3 demonstrate how Member States with a higher penalty have higher biofuel mandate threshold prices, following the calculation derived in Section 3.1.2. Since Hungary had the highest penalty of all assessed Member States, it also has the highest biofuel mandate threshold price for ethanol, HVO, and FAME. Consequently, fuel suppliers in countries with a lower penalty, such as Croatia, have lower biofuel mandate threshold prices and are therefore not willing to pay as much per litre of biofuel due to the low incentives to meet biofuel blending mandates. In the case of fuel suppliers in Austria and Sweden, both are theoretically willing to pay more for ethanol than for HVO and FAME, which correlates to both countries having higher penalties on biofuel blending in petrol than in diesel.

As Germany and Sweden have GHG emission reduction mandates, biofuels with a higher environmental performance have a higher biofuel mandate threshold price. This is because a GHG emission reduction mandate favours a fuel with lower lifecycle emissions (i.e., total emissions accumulated during the biofuel's production, operation, and disposal), as less amounts of fuel are needed to achieve the desired emission reduction. Because of this, fuel suppliers are incentivised to use better performing fuels in their blends which is reflected in a higher biofuel mandate threshold price. This is evident when analysing Figure 4.3 b), as HVO is assumed to have lower lifecycle emissions than FAME, corresponding to the difference in threshold price indicated for HVO and FAME in these two countries. Fuel suppliers in the remaining countries, which have another type of blending mandate not motivated by the fuels' environmental performance, do not have any particular interest in paying more for HVO than for FAME. This is illustrated in Figure 4.3 b) as an identical threshold price for the two fuels.

Looking at the EU average price for ethanol in Figure 4.3 a), one can see that it is much lower than the biofuel threshold prices in most countries, except for Croatia. This means that even if fuel suppliers in many Member States are theoretically willing to pay a higher per litre of ethanol to avoid the penalty, in reality they do not pay this higher price. This could point to a stabilised market where supply matches demand. However, in Figure 4.3 b), the average prices for FAME and HVO in the EU are higher than the average price of ethanol, and are much closer to the biofuel mandate threshold price in many countries, such as France, Luxembourg and Sweden. Considering the average price of HVO, as it is higher than the biofuel mandate threshold price of HVO in Austria, Belgium, and Italy, fuel suppliers in these countries are likely to only blend in FAME in their diesel mixes, as it would not be cost-effective to use HVO.

4.2.1.1 Sensitivity Analysis of the Biofuel Mandate Threshold Price

Figure 4.4 illustrates how the biofuel mandate threshold price is affected by an increase or a decrease in fuel lifecycle emissions. In this example, a sensitivity analysis of the prices of HVO and FAME on the Swedish biofuel market was performed. Sweden was chosen in this case study because the country has a GHG emission reduction mandate, with the highest biodiesel blending mandate in the EU. Therefore, it is of interest to investigate how changes in lifecycle emissions are connected to the biofuel mandate threshold price. The horizontal lines in Figure 4.4 refer to the base cases stemming from fuels used in Sweden in 2022:

- HVO with lifecycle emissions of 0.23 kg CO_2-eq/L and a biofuel mandate threshold price of 2.26 €/L.
- FAME with lifecycle emissions of 0.58 kg CO_2-eq/L and a biofuel mandate threshold price of 2.13 €/L.

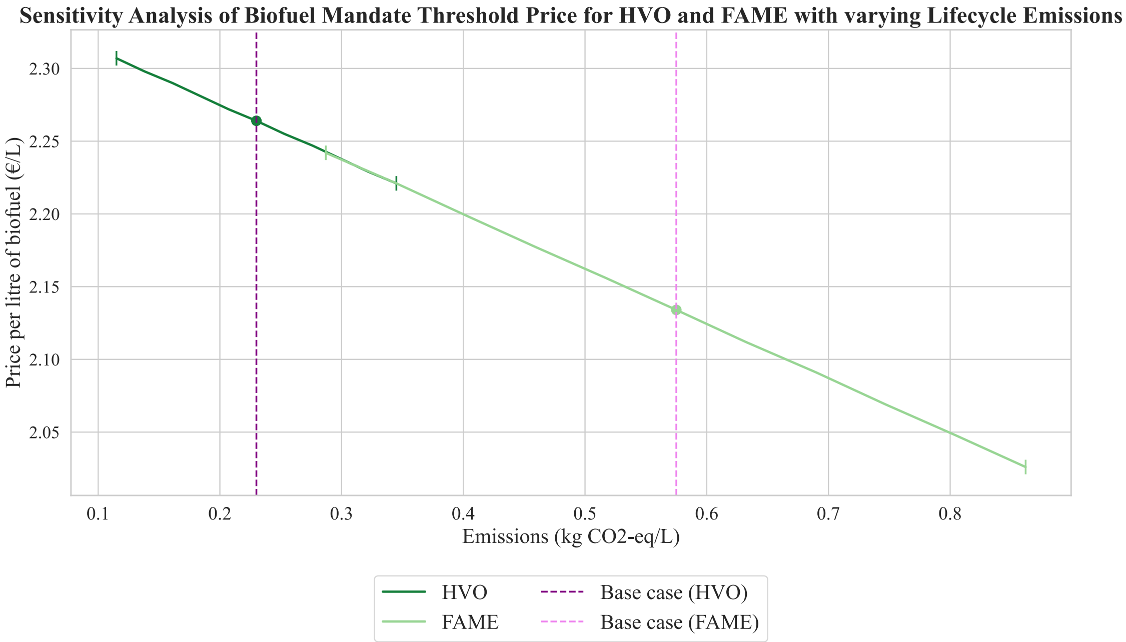


Figure 4.4: Sensitivity analysis on how the biofuel mandate threshold price (y-axis) in €/L is affected by a decrease and an increase in lifecycle emissions (x-axis) in kg CO_2-eq/L when a GHG emission reduction mandate is enforced. The markers illustrate how the biofuel mandate threshold price increases when lifecycle emissions decrease. The horizontal lines illustrates the base cases, which is the fuels used in Sweden in 2022.

As is evident from Figure 4.4, a decrease in lifecycle emissions results in an increase in the threshold price. Contrarily, an increase in lifecycle emissions lowers the biofuel mandate threshold price that fuel suppliers would be willing to pay for the fuel to fulfil the GHG emission reduction mandate. This is because higher lifecycle emissions of the biofuel mean that larger volumes are needed in the blended fuel to fulfil the GHG emission reduction mandate. If fuel suppliers can instead choose a biofuel with lower lifecycle emissions, less amounts are needed to fulfil the mandate, making it cost-effective for fuel suppliers to blend in smaller amounts of the more expensive biofuel than larger amounts of a cheaper biofuel. Furthermore, the analysis highlights how fuel suppliers are more incentivised to pay a higher price for HVO than for FAME, following the above reasoning. However, this is true for a well-performing HVO fuel. As illustrated in Figure 4.4, a well-performing FAME fuel could have less lifecycle emissions than a low-performing HVO batch, which results in fuel suppliers then wanting to pay more for FAME than for HVO. This supports the statement that a GHG emission reduction mandate favours the blending of biofuels with a lower emission factor.

4.2.2 Aviation Fuel

The biofuel mandate threshold price per litre of SAF is illustrated in Figure 4.5. Similarly to road transport fuels, a higher penalty results in a higher threshold price, meaning that fuel suppliers are theoretically willing to pay a higher price for a biofuel if the penalty is higher.

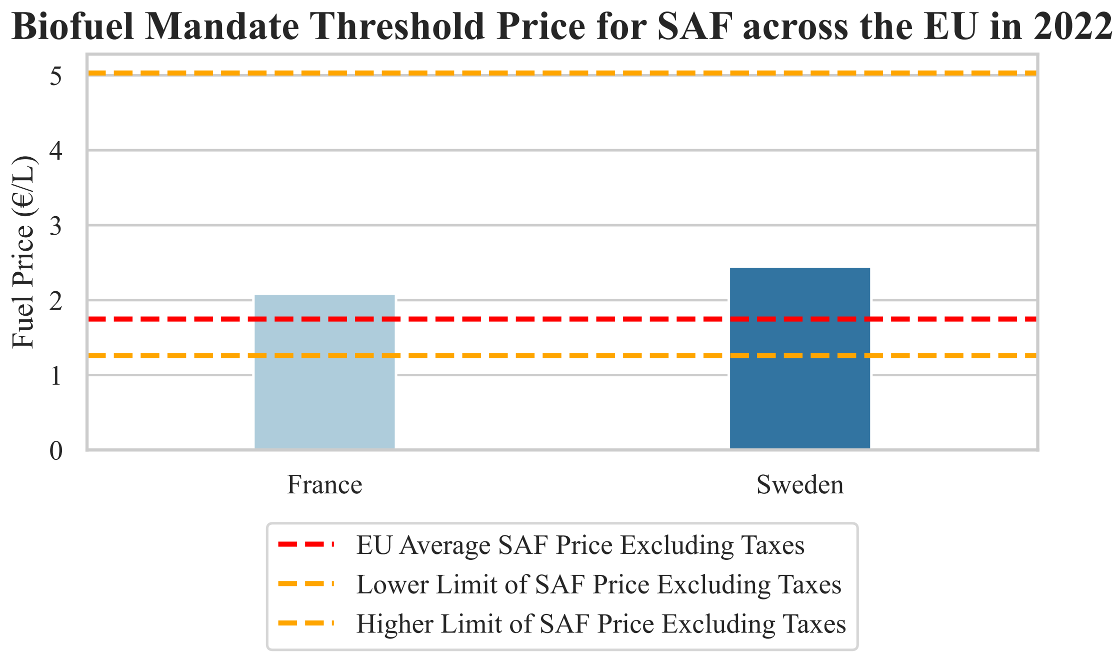


Figure 4.5: Biofuel mandate threshold price (y-axis) in €/L that fuel suppliers in France and Sweden (x-axis) are willing to pay for SAF in 2022. The horizontal lines indicates the assumed EU Average SAF price, as well as an indication of the SAF price span due to the volatile market.

As can be seen in Figure 4.5, the biofuel mandate threshold price per litre of SAF is higher in Sweden than in France. This follows the earlier reasoning, as Sweden has a higher penalty than France.

Since SAF production has limited capacity and the technology is in development, this results in price volatility [4]. As earlier mentioned, SAF prices can range from 1.5 to 6 times the fossil price. This can affect the degree of mandate fulfilment, since if the SAF price is higher than the biofuel mandate threshold prices in France and Sweden, it will be more cost-effective to take the penalty instead.

4.3 Comparison of Blended Fuel Prices

This section presents insights on and comparisons of consumer fuel prices across the EU, for both the road transport and aviation sectors.

4.3.1 Road Transport Fuels

The relationship between theoretical maximum prices, actual national prices, and EU average prices for petrol and diesel in EU Member States is shown in Figure 4.6. In Figure 4.6 a) and c) the consumer prices of petrol and diesel are illustrated, respectively, while Figure 4.6 b) and d) illustrate the national consumer prices of petrol and diesel in the countries that were considered not to have per-unit based penalties. Therefore, no theoretical maximum prices could be calculated for these Member States, and only the actual consumer prices are illustrated. The darker bars, rightmost in Figure 4.6 a) and c), illustrate the actual consumer prices at the pump, excluding taxes, showcasing what the fuel price actually ended up being. The lighter bars in Figure 4.6 a) and c) illustrate the blended fuel threshold price, which refers to the calculated consumer prices of blended fuel based on the national fuel shares reported to Eurostat [38], which gives a more realistic view of how the calculated prices compare to the actual prices in every country. The error bars on top of the blended fuel threshold price bars indicate the possible price range, which illustrate the fuel suppliers' choice of how to fulfil the biofuel blending mandate.

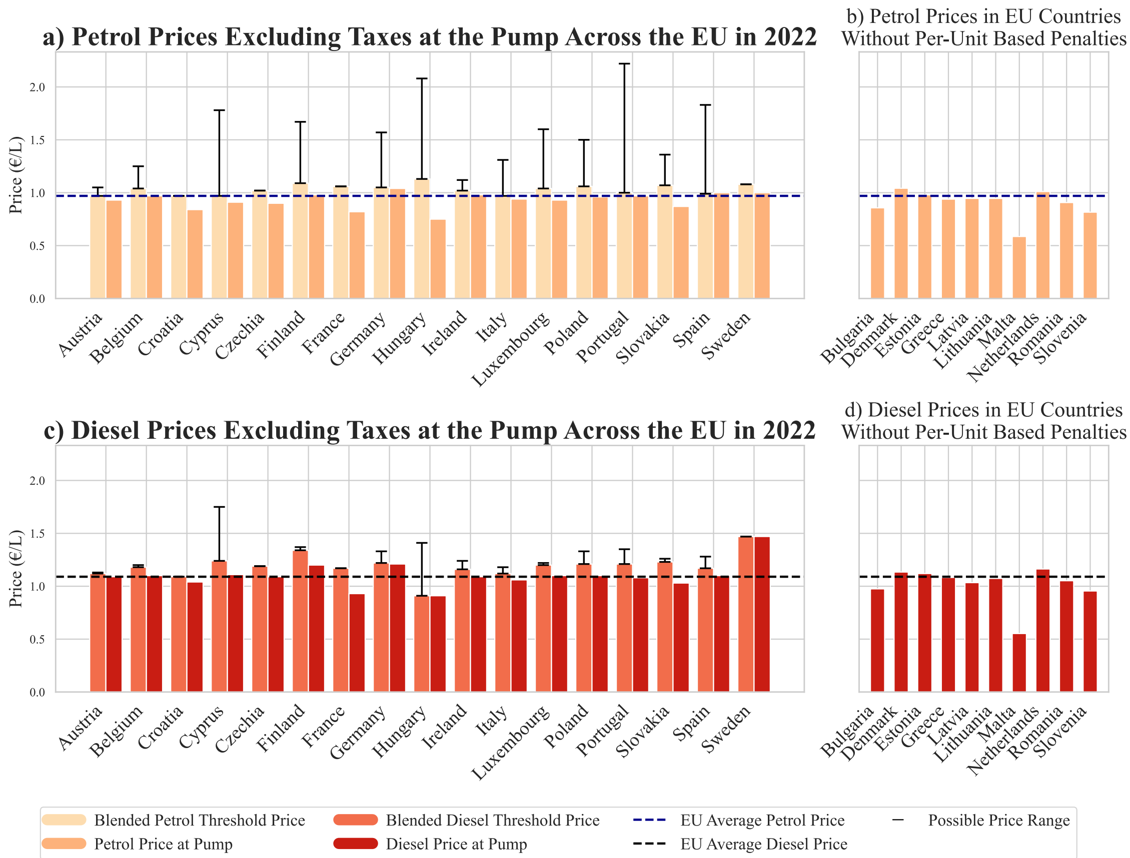


Figure 4.6: Theoretical blended prices in comparison with actual fuel prices at the pump in €/L (y-axis) in 2022 across EU Member States (x-axis), excluding taxes. Figures 4.6 a) and b) demonstrates petrol prices and 4.6 c) and d) diesel prices. Blended fuel threshold prices are calculated based on the actual consumed fuel mixes in each country and the possible price range illustrates fuel supplier's choice. The horizontal lines indicate EU average fuel prices. National fuel prices and EU average prices are retrieved from the Weekly Oil Bulletin [44].

As is evident from Figure 4.6 a) and c), some countries, such as Cyprus, Hungary, Portugal, and Spain, have very large error bars while, for example Austria, Croatia, France, and Sweden, have much smaller error bars. This is affected by national fuel mixes and how fuel suppliers in each country choose to fulfil their respective mandates. If the Member State has solely an overall blending mandate, it is possible for the fuel suppliers to blend in only ethanol in the petrol or biodiesel in the diesel while still fulfilling their blending mandate. However, that would likely result in high fuel prices for either petrol or diesel. This scenario becomes evident in the fuel mixes reported to Eurostat [38], where most fuel suppliers in these Member States chose to blend in both ethanol and biodiesel to meet the mandate. If the country has both an overall mandate and specified petrol and diesel mandates, such as Austria and Belgium, it leaves fuel suppliers with less choices on what biofuels to use and, therefore, the potential price range is smaller. If the country only has specified mandates for petrol and diesel, such as France or Sweden, it removes fuel supplier's flexibility, resulting in no possible price ranges. As the error bars that illustrate the possible price range indicate in Figures 4.6 a) and c), the theoretical diesel prices are, in most cases, significantly closer to the actual fuel prices at the pump, than the petrol prices. This could mean that fuel suppliers choose to blend in more biodiesel than bioethanol in their fuel mixes. For the cases of Cyprus and Hungary, the possible price range is rather high for both petrol and diesel. This could imply that fuel suppliers are not blending in enough biofuels to meet the mandate.

Figures 4.6 b) and d) illustrate how actual consumer prices for petrol and diesel in the ten Member States without per-unit based penalties relate to average fuel prices in the EU. Most of them have fuel prices that are quite close to the EU average, while Malta sticks out as having the lowest fuel prices of all the Member States. This could perhaps be due to fuel subsidies from local authorities. Another country that stick out is Sweden in Figure 4.6 c), with the highest actual consumer price on diesel in all of the Member States.

Focusing on Sweden, one can identify how close the actual Swedish prices of petrol and, in particular, diesel are to the theoretical maximum prices. This demonstrates how the market drove fuel suppliers to pay the biofuel mandate threshold price for FAME and HVO. This is the result of market mechanisms, as there is an increased demand from fuel suppliers to meet the rather high Swedish diesel biofuel blending mandate. In response, the price of the product increases too, if the supply is not big enough. When the price of biofuel increases, it affects the price of the blended fuel which is shown in Figure 4.6 c). Considering that Sweden had the highest consumer price for diesel in the EU in 2022, and the diesel price was almost 35%, or €0.5/L, higher than the EU average diesel price. Since Sweden also has the largest biofuel blending mandate in diesel of the Member States, this price difference is probably connected to the price of biofuels.

Taking into account that consumer prices were pushed so high in Sweden, it can be interpreted as fuel suppliers found it more cost-effective to meet the mandate rather than not complying and paying the penalty instead. This follows the reasoning for the calculation of the biofuel mandate threshold price, as it refers to the maximum price that fuel suppliers would theoretically be willing to pay for biofuels to meet the blending mandate.

4.3.1.1 Sensitivity Analysis of Fossil Fuel Prices

When calculating the blended fuel threshold price, an assumption was made that the price of the fossil component would correspond to the EU average blended fuel price. To evaluate the robustness of this assumption, a sensitivity analysis is conducted to assess how variations in fossil fuel prices influence the resulting blended fuel threshold prices. In this example, Croatia, Hungary, and Sweden were selected, based on their penalty levels. Croatia has the lowest registered per-unit based penalty of the EU Member States while Hungary had the highest. Sweden was selected since the country has a penalty that is somewhere in the middle. Figure 4.7 demonstrates how an increase or a decrease in the price of fossil fuel affects the blended fuel threshold prices for petrol and diesel. The dashed vertical line illustrates the base cases of the prices of the fossil components. For petrol, the fossil component was assumed to have a price of €0.97/L while the price of the diesel component was assumed to be €1.10/L.

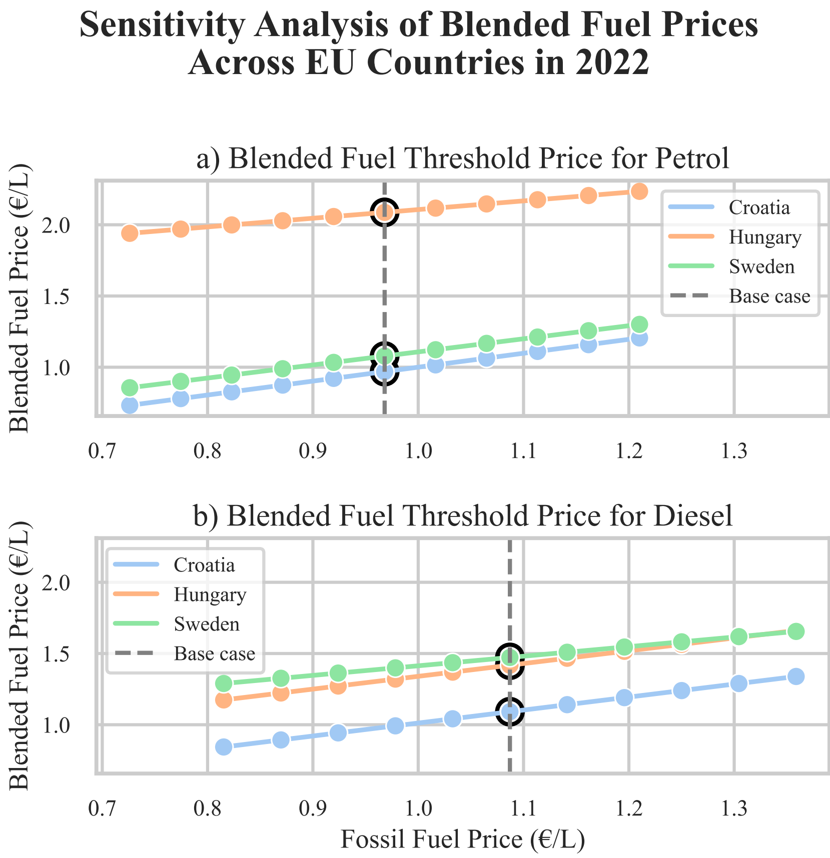


Figure 4.7: Sensitivity analysis of fossil prices for petrol and diesel in €/L (x-axis) in Croatia, Hungary and and Sweden, in relation to blended fuel threshold prices (y-axis), excluding taxes, in 2022. Figure 4.7 a) depicts changes in consumer petrol price and Figure 4.7 b) depicts consumer diesel prices. The dashed vertical line illustrates the assumed prices of the fossil component.

Figure 4.2 illustrates how an increase in the price of fossil fuel results in increased consumer prices, while a decrease in the fossil component results in lower consumer prices. Focusing on Figure 4.7 b), consumer prices for blended diesel fuel in Sweden are less affected by the fossil component price change, than the corresponding consumer prices in Croatia and Hungary. One reason for this result could be the significantly higher Swedish biofuel blending mandate in diesel. Since the price of biofuels is assumed to remain constant, the consumer price of blended fuel in Sweden is less affected by changes in fossil fuel prices, as the blend contains a lower proportion of fossil fuels.

Based on the results of this sensitivity analysis, the assumption of fossil fuel prices of €0.97/L for petrol and €1.10/L for diesel was assumed to be valid. Even with a price variation of ± 25% for the fossil fuels, this results in a change of less than €0.50/L in consumer fuel prices. This indicates that the assumption does not significantly influence the result outcome.

4.3.2 Aviation Fuel

The calculated jet fuel prices for France and Sweden are illustrated in Figure 4.8, where the horizontal line represents the EU average jet fuel price. Since actual national fuel prices are not reported in the same way as in the case of road transport, Figure 4.8 presents only theoretical prices.

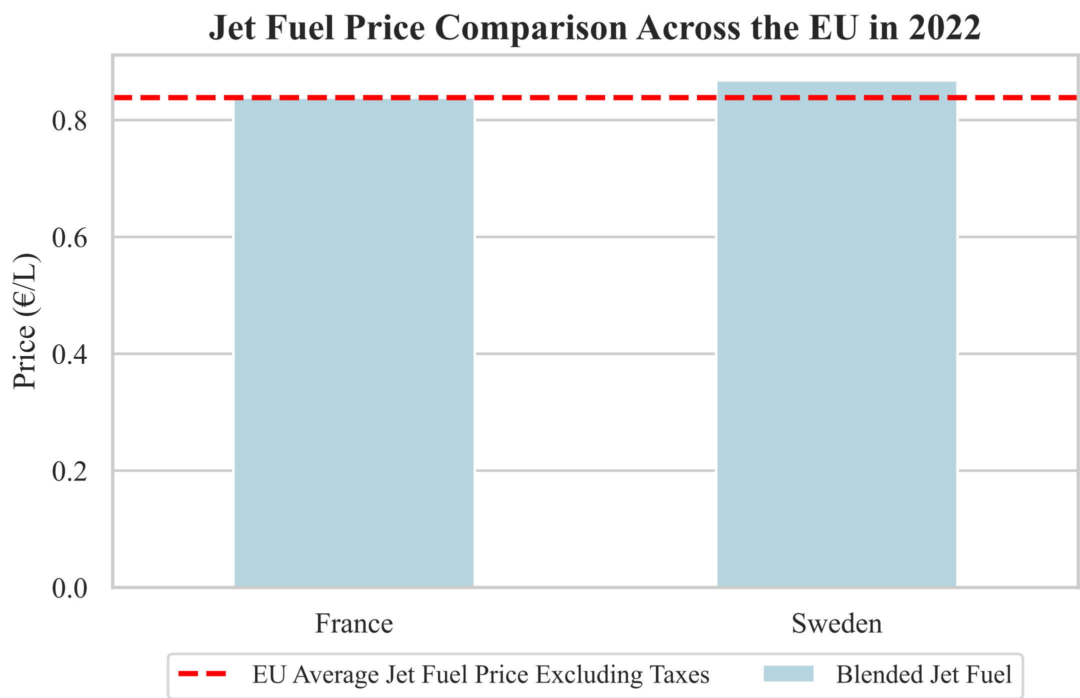


Figure 4.8: Theoretical prices for aviation fuel in €/L (y-axis) excluding taxes in France and Sweden (x-axis), in relation to the EU average jet fuel price in 2022.

Figure 4.8 visualises how the calculated blended jet fuel price compares to the EU average jet fuel price. Jet fuel prices are assumed to have low variability across EU Member States, as it inherently is an international market that allows aircraft to refuel in different countries based on jet fuel pricing. Additionally, since jet fuel is primarily fossil-based, it is less affected by national price fluctuations related to varying biofuel blending mandates, unlike fuels used in road transport. This prevents a comparison of theoretical prices with actual prices, resulting in a comparison with the EU average jet fuel price instead. As is evident from Figure 4.8, the price of French blended jet fuel is close to the EU average price, while the Swedish jet fuel price is slightly higher.

Compared to Figure 4.6, the variation between road transport fuel prices in France and Sweden is greater than for aviation fuel. This could depend on the significantly lower SAF blending mandates, than the biofuel blending mandates for road transport fuels. That results in a higher fossil share in the aviation fuel mix, thereby reducing price differences.

4.4 Fulfilment of National Biofuel Blending Mandates

This section presents comparisons of how well the Member States manage to fulfil their national blending mandates in road transport and aviation.

4.4.1 Road Transport

Figure 4.9 investigates whether the penalty level corresponds to a higher degree of completion of the national biofuel blending mandates. This is demonstrated on a cumulative level to see how close the EU Member States were to fulfilling all of their stated blending mandates. Following the methodology in RED, double counting of biofuels is included for countries with overall mandates as reported to Eurostat. For countries with specific mandates, no double counting was applied, since specific shares including double counting were not reported to Eurostat. Therefore, these countries might reach a higher degree of fulfilment when accounting for double counting. Additionally, double counting is not applied in Denmark, Germany, and Sweden as it is not allowed under a GHG emission reduction mandate.

The x-axes in Figure 4.9 indicate degree of fulfilled mandate on a normalised scale, with the dashed, vertical line illustrating a fulfilled mandate. Figure 4.9 a) represents EU Member States with per-unit based penalties, with the size of the marker corresponding to the magnitude of the mandate. Figure 4.9 b) shows how countries without per-unit based penalties met their mandates, with mandate size on the y-axis.

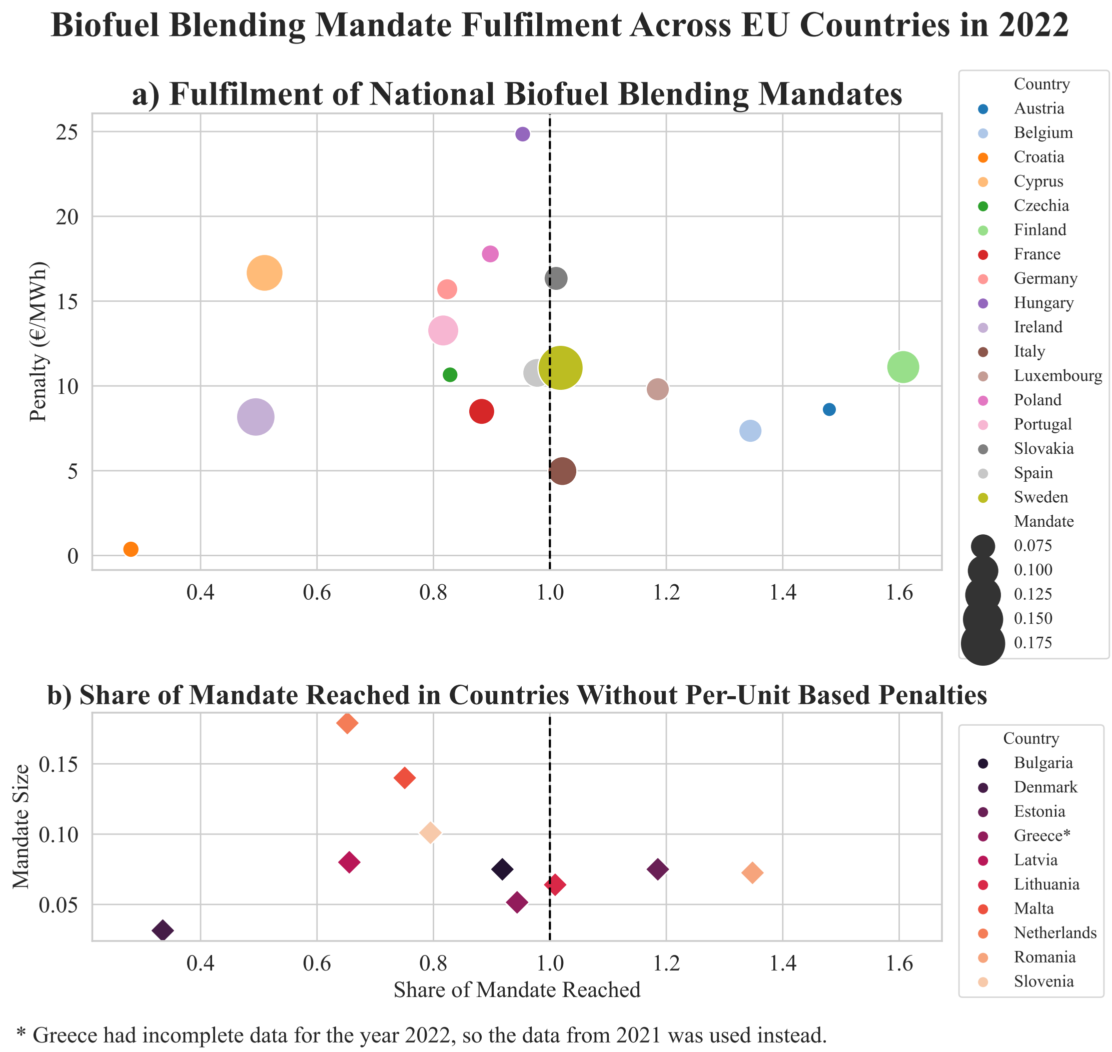


Figure 4.9: Fulfilments of national biofuel blending mandates in 2022 (x-axis). The vertical line represents a fulfilled mandate, illustrating how close the countries came to meeting their respective mandates. Figure 4.9 a) visualizes penalties in €/MWh on the y-axis, extracted from Koster et al. [13]. Figure 4.9 b) demonstrates the level of mandate fulfilment in EU Member States without per-unit based penalties in relation to mandate size (y-axis).

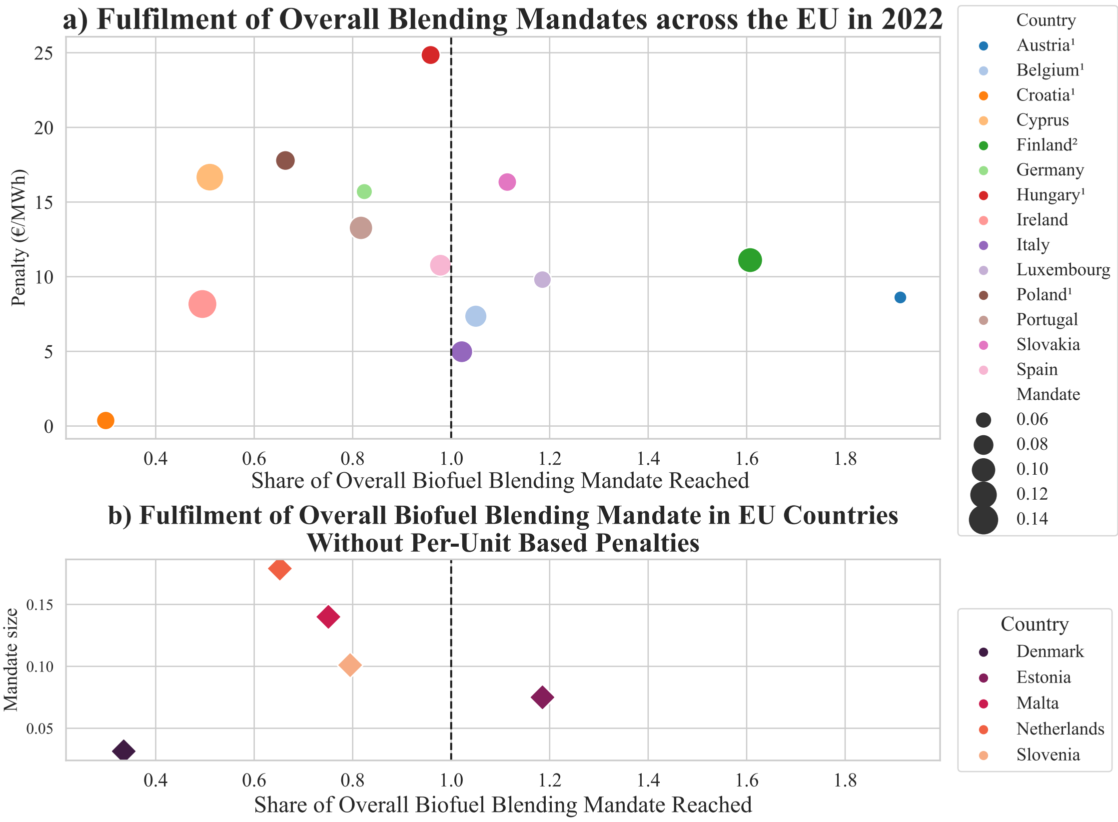
As can be seen in Figure 4.9, most countries do not meet their national biofuel blending mandates, regardless of whether or not a per-unit based penalty was implemented. Four of the Member States, Croatia, Cyprus, Ireland, and Denmark, meet around half or less than half of their respective mandates. Most countries seem to fulfil between 75-95%. Ten countries; Austria, Belgium, Finland, Italy, Luxembourg, Slovakia, Sweden, Estonia, Lithuania, and Romania fulfil their respective mandates. As is evident from Figure 4.9, their penalties are rather similar. Croatia and Hungary are again identified as registering an extreme trend. For those countries, Croatia has the lowest penalty and also meets the least of their mandate, while Hungary has the highest penalty of the Member States but does anyway fail to fulfil their mandate.

Looking back at Figure 4.6, Cyprus had rather high theoretical maximum prices of petrol and diesel, while their actual fuel prices were much lower. This could be because fuel suppliers do not fulfil the blending mandate, and as fossil fuel is cheaper than biofuels, it keeps the consumer prices down. Figure 4.9 demonstrates how Cyprus manages to meet around half of their mandate. That could be the reason for the lower consumer prices, as a lower biofuel content would keep fuel prices down.

In Figure 4.9 a), a trend could be identified in Member States that do not meet their mandates, with an increasing share fulfilled in relation to an increasing penalty level, when looking at Croatia, Ireland, Portugal, Germany, Poland, and Hungary. However, when focusing on the Member States that actually fulfil their mandates, a penalty of around €10/MWh seems to be most effective. On the other hand, Italy has imposed a penalty of €5/MWh and still manages to meet their mandate, while Slovakia has registered a penalty closer to €16/MWh. Both of these penalties seem to be effective since both of the countries manage to meet their mandates, but the difference in penalty level is rather significant. Therefore, discussions arise on whether there are other factors influencing mandate fulfilment, since a lower penalty level seems to be enough in some countries, with in other countries a much higher penalty is required. Of the countries in Figure 4.9 b) that fulfil their mandates, both Romania and Estonia have a penalty range, while Lithuania does not have a penalty in place at all. In the cases of Denmark and the Netherlands, fuel suppliers can be brought to court if they do not follow the blending regulations, but such a penalty is not necessarily effective, since none of the countries fulfils their blending mandates as demonstrated in Figure 4.9 b).

4.4.1.1 Overall and Specific Blending Mandates

To investigate whether there are differences in the degree of mandate fulfilment between overall and specific mandates for petrol and diesel, Figures 4.10 and 4.11 were created. Figure 4.10 visualises fulfilment of overall biofuel blending mandates in EU Member States including double counting, following the RED methodology. Figure 4.10 a) demonstrates how countries with per-unit based penalties fulfilled their overall mandates compared to the penalty level on the y-axis, with marker size illustrating the magnitude of the mandate. Figure 4.10 b) illustrates degree of fulfilment and mandate size on the y-axis for countries without per-unit based penalties.

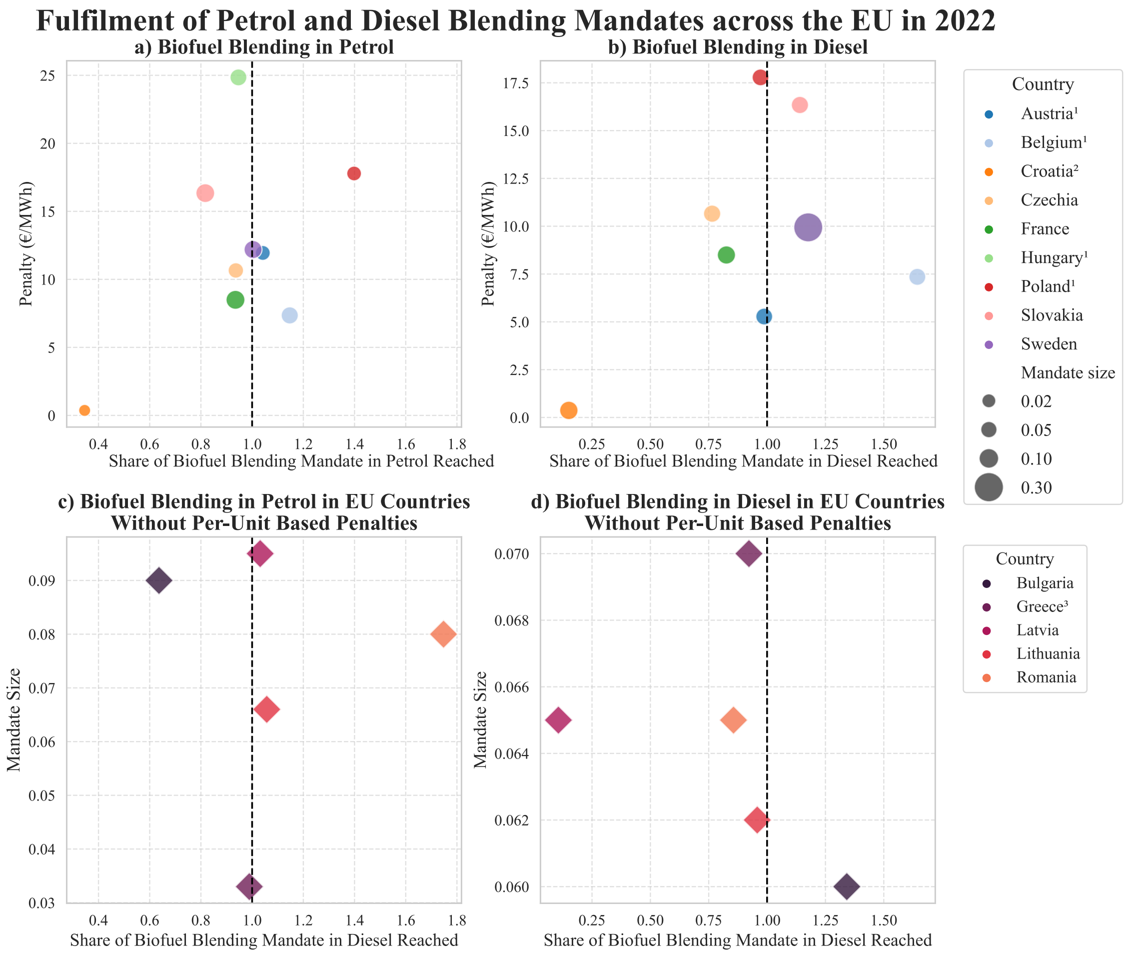


[1] Has additional mandates for petrol and diesel.
[2] Lowered the mandate to address the energy crisis.

Figure 4.10: Fulfilment of overall mandates in EU countries in 2022. Figure 4.10 a) illustrates fulfilment of overall biofuel blending mandate (x-axis) in relation to the penalty (y-axis) in €/MWh, with the size of the marker illustrating mandate magnitude. Penalties are retrieved from Koster et al. [13]. Figure 4.10 b) illustrates how countries without per-unit based penalties fulfils their overall blending mandates (x-axis), in relation to mandate size (y-axis).

Figure 4.10 demonstrates a varying degree of overall mandate fulfilment across EU Member States. Approximately half of the countries in Figure 4.10 a) manages to fulfil their overall biofuel blending mandates, while Figure 4.10 b) demonstrates how only Estonia manages to meet their mandate out of the five countries without per-unit based penalties.

Figure 4.11 demonstrates the degree of fulfilment of specific petrol and diesel mandates. Figures 4.11 a) and b) illustrate fulfilment compared with penalty level, with the size of the marker corresponding to the magnitude of the mandate. Figures 4.11 b) and d) illustrate the degree of fulfilment in the Member States without per-unit based penalties, with mandate size on the y-axis.



[1] Has an additional overall biofuel blending mandate.
[2] Removed their biofuel blending mandates in response to the energy crisis. The marker illustrates fulfilment of the mandate if it had not been removed.
[3] Greece had incomplete data for the year 2022, so the data from 2021 was used instead.

Figure 4.11: Fulfilment of specified mandates in EU countries in 2022. Figures 4.11 a) and b) illustrates fulfilment of specific biofuel blending mandates in petrol and diesel (x-axis) in relation to penalties in €/MWh on the y-axis. Penalties are retrieved from Koster et al. [13]. Figures 4.11 c) and d) illustrates how countries without per-unit based penalties fulfils their petrol and diesel mandates (x-axis), in relation to mandate size (y-axis).

Comparing Figures 4.10 a) and 4.11 a) and b), it is clear that more countries either fulfil, or are closer to fulfilling, their specified biofuel blending mandates for petrol and diesel rather than their overall mandates. Especially in Figure 4.11 a), a majority of the countries are very close to fulfilling their petrol blending mandate. This could be due to slight differences in national legislation in terms of what is allowed to be double counted compared to what is double counted in the Eurostat dataset [39]. In reality, some of these countries might have actually fulfilled their mandates, according to their own legislation.

The same trend seems to follow in Figures 4.10 b) and 4.11 c) and d), when looking at the countries without per-unit based penalties. Only Estonia manages to fulfil their overall biofuel blending mandate, while the petrol blending mandate is met by all countries except Bulgaria. Looking at the diesel blending mandate, Latvia is the country furthest away from meeting their national mandate.

Comparing Figures 4.10 a) and 4.11 a), one can see how Croatia consistently is the Member State that fulfils the least of their biofuel blending mandate, both when it comes to their overall mandate and the specific mandates for petrol and diesel. As their penalty is the lowest of all the Member States with per-unit based penalties, it could mean that it is too low and, therefore, it is not economically justifiable for fuel suppliers to buy biofuels and meet the blending mandate.

4.4.1.2 Case study of Sweden

Figure 4.12 demonstrate how the Swedish fulfilment of petrol and diesel mandates has evolved during the period 2018-2023. Figure 4.12 a) illustrates the petrol blending mandates while Figure 4.12 b) shows the diesel blending mandates. As earlier mentioned, high-blend biofuels are not allowed to be calculated into the fulfilment of the GHG emission reduction mandate, but reported consumed fuel shares do not distinguish between pure and blended biofuels. Therefore, the degree of mandate fulfilment might be a bit lower in reality.

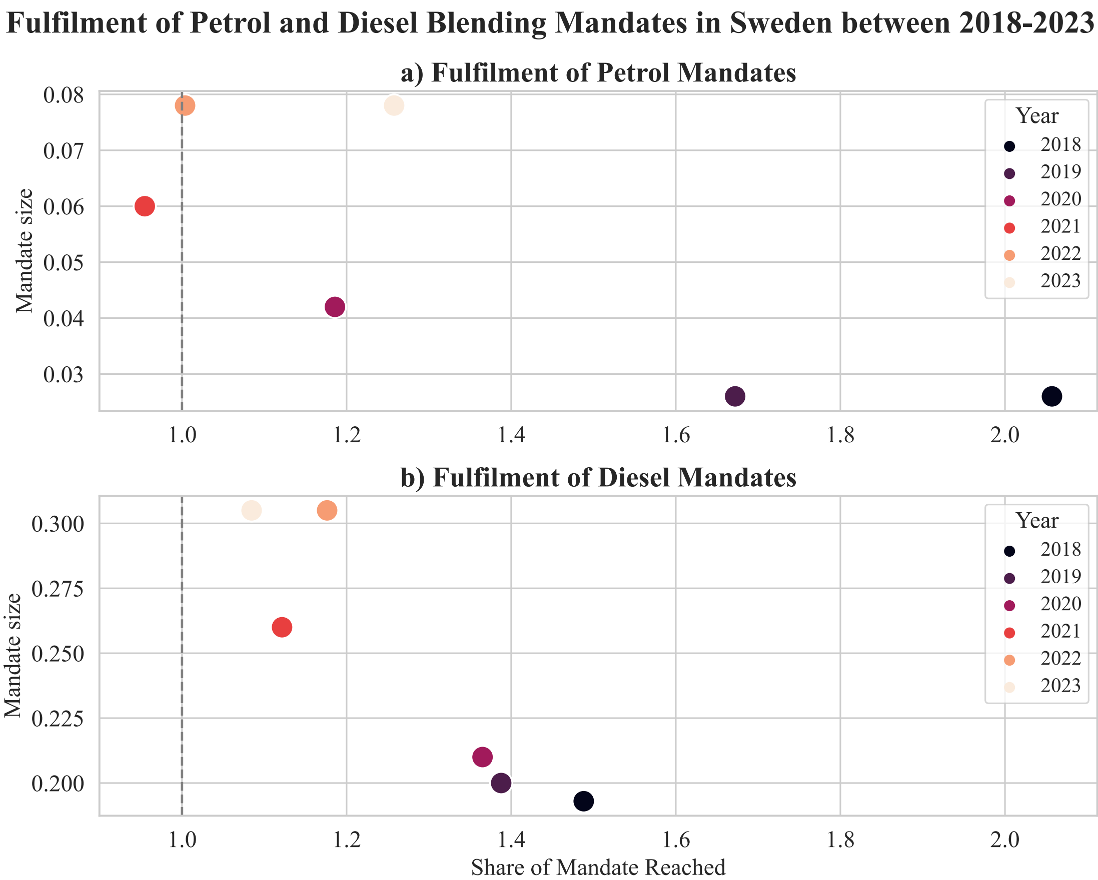


Figure 4.12: Fulfilment of biofuel blending mandates in Sweden during the years 2018-2022 (x-axis) in relation to mandate size (y-axis). Figure 4.12 a) illustrates the petrol mandate and Figure 4.12 b) the diesel mandate.

In general, Sweden manages to meet the national petrol and diesel mandates, as depicted in Figures 4.12 a) and b). The exception is the petrol mandate in 2021, even though Sweden fulfils more than 95% of the mandate. As biofuel blending mandates increase each year, a trend can be identified. Visible in both Figures 4.12 a) and b), the degree of fulfilment decreases as the size of the mandate increases, with the exception of the degree of fulfilment of the diesel mandate in 2022 and the petrol mandate in 2023. This trend may have arisen because it is harder for fuel suppliers to meet higher mandates. However, since fuel suppliers still manage to create fuel blends that meet the biofuel blending mandates even when they were at their highest levels in 2023, it indicates there are large volumes available on the market. Compared to blending mandates in the other EU-27 Member States (stated in Appendix C), the Swedish petrol mandate is a bit on the higher side, while the diesel blending mandate is the highest out of all the assessed countries. This illustrates how it is possible to comply with a high blending mandate. Another possible explanation for the trend is that more and more biofuels with lower emission factors are available, thus reducing the amount of biofuel needed and increasing the possibility for fuel suppliers to fulfil the mandates more precisely.

4.4.2 Aviation

Figure 4.13 illustrates how France and Sweden fulfilled their SAF blending mandates in 2022.

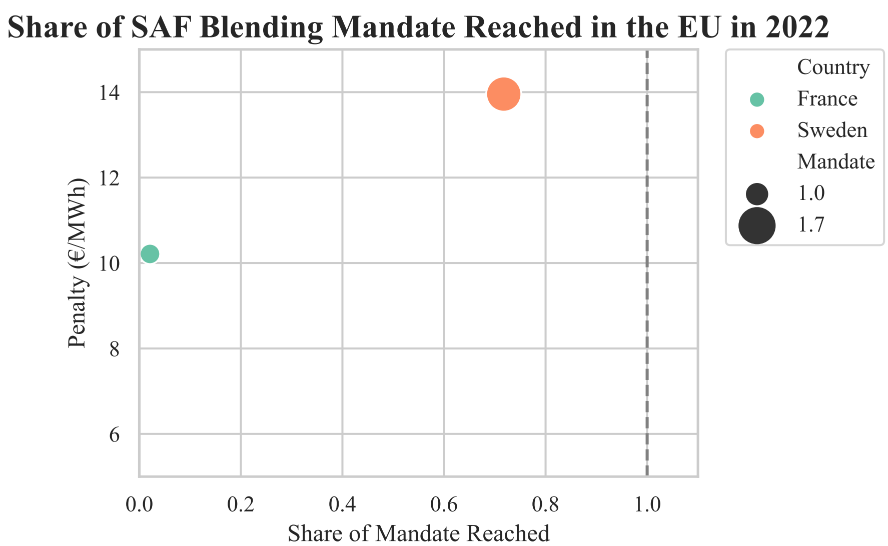


Figure 4.13: Fulfilment of SAF mandates in France and Sweden in 2022 (x-axis) in relation to penalty level in €/MWh (y-axis), with the size of the marker illustrating mandate size. Penalties are retrieved from Koster et al. [13].

Figure 4.13 demonstrate how Sweden reaches more than 70% of their mandate, while France reaches barely 2%. This could be an effect of the early developing SAF market, and that there was not enough fuel available to meet the demand, or that it was too expensive and exceeded the biofuel mandate threshold price and fuel suppliers chose to pay the penalty instead.

5

Discussion and Concluding Remarks

This chapter aims to deepen the understanding of the results presented previously and to conclude and summarise the findings. It will contribute to meeting the aim of this thesis by answering and reflecting on the research questions and identifying the limitations of this work.

5.1 RQ1: Penalties for Non-Compliance with Biofuel Blending Mandates

Answering the RQ: *What are the penalties for non-compliance with biofuel blending mandates implemented in various EU Member States and sectors?*

National penalties for non-compliance vary greatly in size and design between countries. Of the 27 Member States included in the analysis, 17 countries had penalties on road transport fuels that were stated on a per-unit basis, either as energy content (€/MJ), volume (€/L) or GHG emission reduction (€/kg CO_2-eq). These penalties could be transformed into the common unit €/MWh. The remaining ten had penalties that were not given on a per-unit basis. Three out of the 17 Member States with per-unit based penalties; Austria, Poland, and Sweden, have separate penalties for petrol and diesel, while the remaining Member States have a general penalty. Austria and Sweden have higher penalties for petrol than for diesel, while Poland has the same level for both fuels. For the case of Austria and Sweden, the higher petrol penalty could point to a higher incentive for fuel suppliers to meet the petrol blending mandate than the diesel mandate. Regarding the other Member States with per-unit based penalties, Croatia has the lowest recorded penalty of less than €1/MWh while Hungary has the highest penalty of almost €25/MWh, as depicted in Figure 4.1. An average penalty level seems to be around €10/MWh, with countries such as Czechia, Finland, Luxembourg, Spain, and Sweden registering national penalties at that level.

For the case of aviation transport, only France and Sweden had penalties enforced during 2022. The Swedish penalty is a bit higher than the French one, but since there are only two penalties to compare, it is not possible to conclude whether the penalties are high or low. Compared to road transport, both France and Sweden have higher penalties for non-compliance with the SAF blending mandate, which could be because aviation fuels are more expensive than road transport fuels.

5.2 RQ2: Biofuel Mandate Threshold Price

Answering the RQ: *What is the maximum price an actor responsible for fulfilling a blending mandate would be willing to pay for biofuel to avoid a given penalty, and how does this impact the price of blended fuel?*

The level of the biofuel mandate threshold price corresponds to the penalty level, as fuel suppliers in Member States with higher penalties have an increased economic incentive to pay more for the biofuel to avoid the penalty. This trend becomes clear when studying Croatia and Hungary. The two countries have registered the lowest and highest penalty and therefore have the lowest and highest biofuel mandate threshold prices, respectively. Based on the penalty levels in Austria and Sweden, they are the only two countries that have a higher biofuel mandate threshold price for ethanol than for HVO and FAME. However, since the difference in penalties for petrol and diesel is lower in Sweden than in Austria, the difference in biofuel mandate threshold price between ethanol and biodiesel is lower. The remaining countries have a higher biofuel threshold price for HVO and FAME than that for ethanol. In correlation with that, the EU average price per litre of HVO and FAME is higher than that for ethanol.

In Sweden, there are records of how many infringements the reduction mandate had, and then one can draw the conclusion that the penalty was high enough to motivate fuel suppliers to pay the biofuel price rather than taking the penalty. Compared to SAF, where many offences were reported, this points to the SAF price being too high, and it was economically justified for the supplier to face the penalty instead. Although, an important aspect to acknowledge when assessing penalties and the biofuel mandate threshold price is highlighted by Konjunkturinstitutet [48]. The report points to the fact that fuel suppliers might feel stigmatised by the penalty and therefore choose to pay a price that exceeds the biofuel mandate threshold price, even if it is not the cost-effective option, to avoid having to be fined.

The current SAF market is very volatile and production technology and capacity is still under development. This results in a price span that could range up to six times the price of the fossil fuel. To counteract this, the penalties in France and Sweden would have to increase significantly. However, if the SAF price is at the lower end of the span at 1.5 times the fossil price, the penalties are high enough to incentivise fuel suppliers to buy the fuel.

5.3 RQ3: Maximum and Actual Consumer Fuel Prices

Answering the RQ: *How do actual consumer prices on fuels in relevant EU Member States compare to the maximum consumer prices calculated for blended fuel, based on national penalty levels?*

Depending on the type of mandate (overall biofuel blending, specific mandates for petrol and diesel, or a combination), the theoretical prices on blended fuel may vary significantly. In Member States with overall blending mandates, fuel suppliers can choose to fulfil the mandate by only blending in ethanol or biodiesels. This could result in steep increases in consumer prices, and when investigating actual consumed fuel shares, it became evident that fuel suppliers most often blended in biofuels in both petrol and diesel. In countries with specific mandates for petrol and diesel, this leaves no room for fuel suppliers to decide on how to fulfil the mandates, and it results in no variations in blended fuel prices. The Swedish diesel price stands out as the actual consumer price is close to the theoretical price. This was the result of a market where demand pushed forced up the fuel prices, which resulted in high consumer prices.

Due to the volatile market, the range of SAF prices could potentially greatly affect the price of blended aviation fuel. However, since the blending mandates in France and Sweden were quite small in 2022, it did not have a significant influence on the blended fuel price. Since the aviation fuel market is international to a higher degree than the road transport fuel market, as well as the small share of SAF in total fuel consumption, the prices of current fuel mixes in France and Sweden have not increased notably.

5.4 RQ4: Contribution of Penalties on Fulfilment of Biofuel Blending Mandates

Answering the RQ: *How do specific penalties contribute to biofuel usage and the fulfilment of blending mandates in different Member States and sectors?*

The implemented penalties across EU Member States range between less than €1/MWh in Croatia and €25/MWh in Hungary. Based on this, a hypothesis could be that Croatia would have the lowest degree of mandate fulfilment, while fuel suppliers in Hungary would be strongly motivated to fulfil their blending mandates. However, it became evident that while Croatia is the Member State to fulfil the least of their mandate, Hungary is not the country with the highest degree of fulfilment. Looking at Austria, where the penalty for petrol is higher than that for diesel, it should result in a higher share of the petrol mandate met. In this case, Austria slightly over fulfils their petrol mandate, and just meet their diesel mandate.

Based on the countries that fulfils their mandates, a penalty of around €10/MWh seems to be most effective. However, Italy has registered a lower penalty of €5/MWh and Slovakia a higher penalty of €16/MWh and both of those countries manage to meet their mandates. On the other hand, Czechia also has a penalty of €10/MWh, but does not fulfil their mandate. Even if the penalty is a policy tool for ensuring mandate compliance, the penalty level does not seem to be the only factor that affects the degree of mandate fulfilment.

The penalties for non-compliance with blending mandates in aviation are higher in France and Sweden, compared to their road transport penalties. However, both France and Sweden fulfil less of their SAF blending mandates than their respective road transport mandates. One reason for this could be the price difference between biofuels for road transport and SAF. Due to the volatility of the SAF market, as it is still under development, the low degree of mandate fulfilment in France and Sweden could be because there were not enough SAF on the market to meet demand. If demand is high, it will drive up the prices on SAF, and if the prices become too high, fuel suppliers will instead opt to pay the penalty. To increase the degree of fulfilment, the penalty could be increased to incentivise fuel suppliers to continue to purchase SAF even if the rising demand results in higher prices. However, as identified in the road transport sector, it does not seem that higher penalties are directly in correlation with a higher degree of mandate fulfilment. If the aviation sector behaves similarly to the road transport sector, a penalty that is not extremely high seems to achieve the highest fulfilment. As more and more countries are planning to implement SAF blending mandates, producers must scale up the production of fuel as demand increases. If not, this will cause a steep price increase for an already expensive fuel. If the SAF price is higher than the biofuel mandate price, fuel suppliers will instead choose the penalty and, therefore, will not meet the blending mandates. Since only France and Sweden have implemented penalties, it is not yet possible to identify an average penalty. The penalty would also need to adapt to the future SAF price, when the market has stabilised and is not as volatile as it is today.

5.5 Comparison with Previous Studies

This thesis expands the previous understandings of the European Commission [15], Ebadian et al. [16] and Lundberg et al. [9] regarding the importance of biofuel blending mandates by investigating the role of penalties. This study explores how variations in the implementations of blending mandates and penalty levels affect the outcomes of mandate fulfilment in the road transport and aviation sectors. Furthermore, this thesis provides an overview of biofuel blending mandates in all 27 EU Member States, since the work of the European Commission [15] and Ebadian et al. [16] only covers a few selected Member States. In contrast to Lundberg et al. [9], this study investigates penalties more deeply as a policy tool and provides a comprehensive analysis of how penalty levels correspond to mandate fulfilment. Additionally, this study provides insight into the aviation sector. Biofuels are not as widespread in that sector as in road transport, and the findings of this thesis point to the connections between policy implementation and the importance of market development.

5.6 General Reflections

The aim of this thesis was to investigate the impact of biofuel blending mandates and penalties for non-compliance with said mandates in the EU. While all 27 Member States have implemented blending mandates, design and levels vary across countries. Regarding the penalties for non-compliance, the design and level vary significantly across the Member States. Furthermore, this thesis explores how blending mandate design and penalty levels are connected to degree of mandate fulfilment. Although penalties are a central tool for ensuring compliance with stated mandates, this study did not find a straightforward correlation between penalty levels and the degree of mandate fulfilment. There appear to be more factors that influence the outcome, such as fuel prices and supply. The importance of stable markets and fuel prices became clear when analysing the aviation sector, as it remains in the early stages of biofuel adoption. Small-scale production in combination with volatile prices hinders the broad adoption of biofuels in the aviation sector, making it difficult for Member States to fulfil their blending mandates. However, if the SAF production increases and the market stabilises, it has the potential to significantly reduce emissions from aviation if more countries impose blending mandates.

In general, this thesis highlights the complexity of policy design and penalties as a tool. While penalties alone might not guarantee mandate fulfilment, they can be implemented as an aid in the establishment of biofuel markets and increasing competitiveness. Going forward, careful developments of policies and market dynamics will be essential in achieving emission reductions through the integration of biofuels across the transport sector.

5.7 Limitations and Future Work

During the progress of this thesis, a few limitations and uncertainties arose. This section aims to address these issues, which can be investigated more closely in future work.

One limitation that appeared early was the quantification of penalties. As ten countries did not have per-unit based penalties, they had to be excluded from some of the penalty-based analyses. By quantifying more types of penalties, it gives a deeper understanding of the effectiveness of different types of penalties in different countries. In addition, it would provide insight on how the penalty system works in Member States with a set fine or a fine range, as this thesis did not manage to identify an application system for these types of penalties.

Due to time limitations, the scope of this thesis had to be rather narrow. If the scope had been expanded, it could have included a longer time perspective. The conclusions drawn in this thesis were only based on data from 2022, which may have affected the results. To increase credibility and relevance, the time horizon could have been extended both backward and forward to identify significant and persistent trends. If the time span is extended to include the future, it could provide insight into how future biofuel markets are affected by blending mandates and how the developing markets for HVO and SAF will respond to increasing demand. An example of this is the sensitivity analysis performed on biofuel mandate threshold prices of HVO and FAME in Sweden. This evaluation can be expanded to include more types of fuel and more countries, to gain an understanding of how the biofuel mandate threshold price might affect biofuel markets. Another possible scope expansion could have been to include the shipping sector. This would have broadened the understanding of the decarbonisation of the transport sector. It could also highlight how progress and initiatives differ between different parts of the transport sector and whether legislations differ between sectors.

This thesis was carried out at an EU Member State level, to gain perspectives on how Member States have implemented biofuel blending mandates. As only Sweden was selected for a deeper analysis, this could have led to overlooked insights on a country-specific level. For example, national legislation to promote certain feedstock production could affect mandate fulfilment or penalty levels if governments want to steer the fuel consumption in a specific direction. Another interesting aspect that could be addressed in future studies is the continuation of the deeper analysis of Sweden. Sweden has been the EU Member State with the highest share of renewable energy in the transport sector, but lowered their biofuel blending mandates in 2024. Therefore, it could be interesting to investigate how the mandate reduction affected biofuel consumption and fuel prices, and if other initiatives were implemented to reduce the emissions from the sector and, in that case, how effective those solutions were.

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A

Appendix 1

This Appendix contains the constants used when producing the results stated in Chapter 4 *Results*, to bring transparency and reproducibility to the thesis.

A.1 Fuel Characteristics

When calculating the results for countries with a GHG emission reduction mandate (Denmark, Germany, and Sweden), the data in Table A.1 was used.

Table A.1: Data used when calculating results in countries with a GHG emission reduction mandate.

	Energy content [MJ/L]	**Emissions [g CO2-eq/MJ]**	**Emissions [g CO2-eq/L]**	**Reference**
Diesel	35.3	95.1	-	[35]
HVO	34.4	6.7	229.8	[36]
FAME	33.0	17.4	574.6	[36]
Petrol	32.2	93.3	-	[35]
Ethanol	21.0	5.7	120.4	[36]
Aviation fuel	34.6	89	-	[35]
SAF	33.8	6.8	230.7	[36]

The case study on road transport mandate fulfilment in Sweden utilized annual emission factors and fuel shares retrieved from the Swedish Energy Agency [47], to capture the development of lifecycle emissions in better performing fuels. To acknowledge the blending of ethanol and biogasoline in petrol, as well as HVO and FAME in diesel, fuel shares were weighted when calculating diesel emissions. Table A.2 presents the development of the emission factors in ethanol while Table A.3 presents the emission factors and fuel shares for HVO and FAME used in Swedish diesel.

Table A.2: Emission factors and fuel shares for ethanol and biogasoline used when calculating mandate fulfilment in Sweden during 2018-2023. Data retrieved from the Swedish Energy Agency [47].

Year	Emission factor Ethanol [g CO2-eq/MJ]	Volume Ethanol [m3]	Emission factor Biogasoline [g CO2-eq/MJ]	Volume Biogasoline [m3]
2018	0.261	76 248	0.193	7 266
2019	0.266	143 311	0.181	9 724
2020	0.194	137 037	0.183	50 887
2021	0.106	192 865	0.092	31 050
2022	0.06	261 357	0.067	63 403
2023	0.032	254 173	0.049	135 218

Table A.3: Emission factors and fuel shares for HVO and FAME used when calculating mandate fulfilment in Sweden during 2018-2023. Data retrieved from the Swedish Energy Agency [47].

Year	Emission factor FAME [g CO2-eq/MJ]	Volume FAME [m3]	Emission factor HVO [g CO2-eq/MJ]	Volume HVO [m3]
2018	0.278	173 025	0.071	535 347
2019	0.255	344 336	0.070	1 058 132
2020	0.277	315 024	0.076	1 092 652
2021	0.229	283 326	0.062	1 326 277
2022	0.174	277 407	0.067	1 642 347
2023	0.195	279 625	0.070	1 355 498

When calculating results in countries with an energy or volume-based biofuel blending mandate, the data in Table A.4 was used.

Table A.4: Data used when calculating results in countries with an energy or a volume-based biofuel blending mandate.

	Emissions [g CO2-eq/MJ]	Reference	Energy content [MJ/L]	Reference
Diesel	95.1	[10]	36	[27]
HVO	10.1	[10]	34	[27]
FAME	25.1	[10]	33	[27]
Petrol	93.3	[10]	32	[27]
Ethanol	20.8	[10]	21	[27]
Aviation fuel	-	-	34	[27]
SAF (HVO)	6.8	[36]	34	[27]

The EU average prices for the road transport biofuels included in this thesis are presented in Table A.5.

Table A.5: EU average biofuel prices.

Fuel type	Annual average price in Europe [SEK/L]	Reference
Ethanol	11	[49]
FAME	17	[49]
HVO	22	[49]

Table A.6 presents the constants used to identify aviation fuel prices.

Table A.6: Data used in the calculations on aviation fuel prices.

	Price [USD/t]	Reference	**Density [kg/m3]**	Reference
SAF	2437	[45]	755	[50]
Kerosene	1094	[45]	807	[50]

A.1.1 Conversion Factors

1 toe = 41 868 MJ
1 kWh = 3.6 MJ

A.1.2 Eurostat Datasets

Table A.7: Eurostat datasets used to extract data on fuel consumption in the road transport sector.

Data	**Eurostat dataset [dataset_id]**	**Reference**
Aviation fuel consumption	Final energy consumption in transport by type of fuel [ten00126]	[41]
Biofuel consumption including double counting	Use of renewables for transport – details [nrg_ind_urtd]	[39]
Fuel consumption in the road transport sector	Final energy consumption in road transport by type of fuel [ten00127]	[38]

B

Appendix 2

The equations stated in Chapter 3 *Method* are used to obtain the results presented in Chapter 4 *Results*. How these equations were derived are described in this Appendix.

Included parameters, their denominations and units in the equations.

- Emission intensity of biofuel, E_B [kg CO_2-eq/L fuel]
- Emission intensity of fossil fuel, E_F [kg CO_2-eq/L fuel]
- GHG emission reduction mandate, RM [%]
- Price of fossil fuel, I_F [€/L fuel]
- National set penalty for non-compliance, P [€/kg CO_2-eq]

The obtained variables, their denominations, and units are described below.

- Price of a fuel blend without any biologic component, $\mathrm{I}_{\mathrm{FOSSIL}}$ [€/L fuel]
- Resulting penalty, P_R [€/L fuel]
- Share of biofuel in total fuel blend, X_B [%]

Equation (B.1a) describes the emissions from a blended fuel that complies with the mandate. The equation can be rearranged and simplified to obtain an expression for the share of biofuel in the blended fuel that is needed to fulfil the blending mandate, which can be seen below in Equation (B.1b).

$$(1 - RM) \cdot E_F = (1 - X_B) \cdot E_F + X_B \cdot E_B \tag{B.1a}$$

$$X_B = \frac{E_F \cdot RM}{E_F - E_B} \tag{B.1b}$$

The left-hand side of Equation (B.1a) tells how much emissions must be reduced, according to the given reduction mandate (RM). The right side answers how large the emissions of the fuel will be when a biofuel is mixed into the blended mixture. If the equation is balanced, which means that the GHG emission reduction mandate is met, it can be used to find the share of biofuel in total blended fuel, X_B. To calculate how large the share of biofuel must be in a given blended fuel to fulfil the reduction mandate, this is expressed in Equation (B.1b) by solving for X_B.

If the blended fuel does not meet the biofuel blending mandate, a penalty must be paid. If the enforced mandate is a GHG emission reduction mandate, the penalty is paid on the basis of the amount of GHGs emitted. The size of the penalty that must be paid when the mandate is not met can be expressed as in Equation (B.2).

$$P_R = (X_B \cdot E_B + E_F(RM - X_B)) \cdot P \tag{B.2}$$

Equation (B.2) can also be used to find the maximum price a fuel distributor would pay per litre of fuel if no biofuels are used, if $X_B = 0$. In reality, this would mean that it must be cheaper for the fuel distributor to take the full penalty, rather than buying biofuels to mix into the fuel. The consumer price for the fuel would then be the price of the maximum penalty added to the price of the fossil fuel. If a GHG emission reduction mandate is enforced, Equation (B.3) demonstrates the maximum consumer price of a fuel that does not contain any biofuels.

$$I_{\text{FOSSIL}} = E_F \cdot RM \cdot P + I_F \tag{B.3}$$

C
Appendix 3

This Appendix describes the assessed countries' biofuel blending mandates, their type, and respective penalties. Table C.1 describes the mandates implemented in national legislation in all Member States, while Table C.2 describes the penalties applied for road transport and aviation fuels.

Table C.1: National biofuel blending mandates implemented in EU Member States in 2022. Data extracted from Koster et al. [13] and Lieberz [43].

Country	Type of mandate	Share in petrol (%)	Share in diesel (%)	Overall share (%)	Share in aviation fuel (%)
Austria	Energy	3.4	6.3	5.75	
Belgium	Energy	6.5	6.5	10.2	
Bulgaria	Volume	9	6		
Croatia	Energy	0.1	8.81		
Cyprus	Energy			14	
Czechia	GHG emission reduction (Energy)	0 (4.1)	0 (6.9)	6	
Denmark	GHG emission reduction			3.4	
Estonia	Energy			7.5	
Finland	Energy			12 (19.5)	
France	Energy	9.2	8.4		1
Germany	GHG emission reduction			7	
Greece	Energy Volume	3.3	 7		
Hungary	Energy	6.1	0.2	8.4	
Ireland	Volume			14.9	
Italy	Energy			10	
Latvia	Volume	0 (9.5)	0 (6.5)		
Lithuania	Energy	6.6	6.2	6.8	
Luxembourg	Energy			7.7	
Malta	Energy			14	
Netherlands	Energy			17.9	
Poland	Energy	3.2	6.2	8.8	
Portugal	Energy			11	
Romania	Volume	8	6.5		

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Country	**Type of mandate**	**Share in petrol (%)**	**Share in diesel (%)**	**Overall share (%)**	**Share in aviation fuel (%)**
Slovakia	Energy			8.2	
	Volume	9	6.9		
Slovenia	Energy			10.1	
Spain	Energy			10	
Sweden	GHG emission reduction	7.8	30.5		1.7

Table C.2: Penalties for road transport and aviation in EU Member States in 2022. Data extracted from Koster et al. [13].

Country	**Petrol**	**Diesel**	**Combined penalty**	**Jet**
Austria	€43/GJ	€19/GJ		
Belgium			€900/1000 L	
Bulgaria			200,000 BGN	
Croatia			0.01 HRK/MJ	
Cyprus			€60/GJ	
Czechia			CZK 1/MJ	
Denmark			Fuel suppliers who fail to meet the GHG reduction quotas may be fined and face imposed criminal liability	
Estonia			€1200-10,000,000	
Finland			€0.04/MJ	
France			€104/hl	€125/hl
Germany			€600/t CO2-eq	
Greece			€5000-1,500,000	
Hungary			HUF 35/MJ	
Ireland			€1/L	
Italy			€750/toe	
Latvia			-	
Lithuania			-	
Luxembourg			€1,200/1000 L	
Malta			€100,000	
Netherlands			Fuel suppliers who fail to meet the quota obligation may be taken to court for an economic misdemeanour	
Poland	PLN 0.1/MJ	PLN 0.1/MJ	PLN 0.2/MJ plus the individual fee	
Portugal			€2000/toe	
Romania			RON 70,000-100,000	

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Country	**Petrol**	**Diesel**	**Combined penalty**	**Jet**
Slovakia			€2/L	
Slovenia			-	
Spain			€1,623/toe	
Sweden	SEK 5/kg CO2-eq	SEK 4/kg CO2-eq		SEK 6/kg CO2-eq

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