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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

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Abstract. To achieve the EU's 2050 climate neutrality goal, biofuel use in domestic transport is necessary which has mostly been promoted by biofuel blending mandates. By 2022, all EU Member States had implemented such mandates for road transport fuels, while only two had applied them to aviation fuel. The mandates vary in design, criteria and penalties for non-compliance, resulting in varying impacts on the blended fuel market. This study maps penalties for non-compliance with blending mandates in the road and aviation sectors and assesses their impact on fuel prices and mandate fulfilment. Based on penalty levels, it was estimated how much fuel suppliers are willing to pay for biofuels and the calculated maximum prices on blended fuel were compared to actual consumer prices. While no clear correlation between penalty levels and mandate fulfilment could be found, findings highlight the need for a balanced combination of penalty levels, blending mandates, and policy measures to increase the biofuel share in transport fuels without disrupting fuel markets.

Keywords: Biofuels · Blending Mandates · Fuel Prices · Penalties · Policy

1 Introduction

To promote renewable energy consumption in the European Union (EU), the Renewable Energy Directive (RED) was implemented in 2009 [1]. The RED was revised in 2023 to include new targets for the transport sector to be met in 2030: i) a binding share of 29% renewable energy in final energy consumption, or ii) a binding target of 14.5% reduction of greenhouse gas (GHG) emission intensity, as well as sub-targets for advanced biofuels [2]. In addition to RED, the aviation sector is subject to the ReFuelEU Aviation Regulation [3], mandating a minimum share of 6% sustainable aviation fuel (SAF) in aviation fuel supply at EU airports by 2030, rising to 70% by 2050, and stricter limits imposed on feedstocks used for SAF production compared to the road transport sector

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[3]. Biofuel blending mandates have been introduced across all EU Member States for compliance with the RED [4]. These mandates require fuel suppliers to blend a minimum share of biofuels into their supplied fuels, based on either energy content, volume, or GHG emission reduction. However, in the aviation sector, only France and Sweden had implemented blending mandates in 2022.

In recent years, external factors have further affected the dynamics of biofuel blending mandates. The surge in global energy prices began in 2021, following the COVID-19 pandemic and exacerbated by Russia's invasion of Ukraine, causing high inflation and economic pressures across Europe [5]. In response, several Member States adjusted their blending mandates in 2022, where Croatia lowered its penalty for non-compliance, Finland reduced its blending mandate, Czechia and Latvia dismissed theirs completely, and Sweden froze the planned annual mandate increase [6]. In light of these economic strains, the role of penalties for non-compliance with biofuel blending mandates becomes important as they ultimately set the maximum price fuel suppliers are willing to pay for biofuels, thus potentially influencing the final consumer price.

Previous research highlights biofuel policies as a central tool for the defossilisation of the transport sector (see e.g., [7, 8]). However, few studies explore how fuel markets in the EU are influenced by the varying implementations of biofuel blending mandates. This creates a gap in understanding how the design of mandates at the national level affects biofuel markets and fuel prices. Several country-specific studies on biofuel policies exist, such as Germany [6], the Netherlands [7], and Sweden and Finland [8]. Global overviews also occur [9, 10], however these lack quantitative perspectives. An econometric analysis on biofuel policy and biofuel production was performed, although limited to ethanol [11]. The evolution of national blending mandates in the EU road transport sector between 2009–2020 was investigated, exploring the influence of mandates on biofuel production and consumption, fuel prices and emission reduction [4]. Penalties for non-compliance were though only briefly addressed, their potential impact on biofuel blending mandate fulfilment or fuel prices was not further assessed [4].

The aim of this study is to assess the impact of penalties for non-compliance on biofuel markets in the EU, by comparing penalty levels with blending mandate fulfilment, and calculating biofuel mandate threshold prices (i.e., the highest price a fuel supplier would be willing to pay per liter of biofuel to comply with the biofuel blending mandate). That price is then used to identify the highest price of blended fuels that consumers might face, hereby referred to as the calculated maximum blended fuel price. Accordingly, the main questions to be answered are the following: i) How do penalties contribute to calculated maximum blended fuel prices, and how does that compare to actual consumer fuel prices?, and ii) How do specific penalties contribute to biofuel usage and the fulfilment of blending mandates in different Member States and sectors?

In the context of this study, three biofuels for blending in fossil road transport fuels have been considered: fatty acid methyl ester (FAME) and hydrotreated vegetable oil (HVO) in diesel, and ethanol in petrol. For aviation transport, SAF in the form of hydroprocessed esters and fatty acids (HEFA) is considered, as it currently is the mainly utilised route for SAF production in Europe [9].

2 Methodology

The year 2022 was chosen for the analysis since it was marked by elevated fuel prices, which subsequently led to several Member States reducing their blending mandates. Therefore, it is of interest to investigate the impact on EU fuel markets. National penalties for non-compliance with biofuel blending mandates were collected from [6]. As penalties are typically given as energy-based, volume-based, or GHG emission reduction-based, they were transcribed into a common unit, €/MWh, for comparison.

To investigate the connection between penalties and blending mandate fulfilment, the reported share of consumed biofuels in relation to the national mandate was compared to penalty levels. Following the RED methodology, double counting for biofuel use was included for certain mandate types. Double counting promotes biofuels with lower risk of land-use change or food competition, allowing certain advanced biofuels to count twice towards blending mandates, though eligible fuel types may vary across countries [10]. Double counting is included in overall energy- or volume-based mandates, and excluded in specific petrol, diesel and SAF mandates due to reporting practices. Double counting is not permitted for GHG emission mandates. Biofuel blending mandate fulfilment was calculated as shown in Eq. (1), based on biofuel use reported to Eurostat [13–16].

$$Blending\ Mandate\ Fulfillment = \frac{Biofuel\ share\ reported\ to\ Eurostat}{Biofuel\ blending\ mandate} \quad (1)$$

To investigate the effect of penalties on fuel prices, two reference values were calculated: the maximum blended fuel price (i.e., the highest price a fuel blend could get, when the fuel supplier complies with the blending mandate) and the biofuel mandate threshold price (i.e., the highest price per liter of biofuel that a fuel supplier would, theoretically, be willing to pay to comply with a blending mandate). Taxes were excluded to enable cross-country comparisons, so the resulting fuel prices serve as proxies for final consumer prices. Table 1 presents the parameters included in the calculations, along with their denominations and units.

Table 1. Parameters included in the calculations, their denominations and units.

Parameter	Denomination	Unit
Biofuel mandate threshold price	I_M	€/L fuel
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
Maximum blended fuel price	$I_{BF,Max}$	€/L fuel
National set penalty for non-compliance	P	€/kg CO_2-eq
Price of biofuel	I_B	€/L fuel
Price of fossil fuel	I_F	€/L fuel
Share of biofuel in blended fuel	X_B	%
Volumetric energy density of fossil fuel	D_F	MJ/L

Following Eq. (2), the maximum blended fuel price per liter, $I_{BF,Max}$, is calculated. Reference prices for fossil-based petrol and diesel, as well as national blended fuel prices, were retrieved from the Weekly Oil Bulletin [17]. Both fossil-based petrol and diesel prices assumed 2022 EU averages, €0.97/L and €1.10/L, respectively.

$$I_{BF,\mathrm{Max}} = (1 - X_B) \bullet I_F + X_B \bullet I_B \tag{2}$$

Under an overall biofuel blending mandate, fuel suppliers can choose how to comply with the mandate by blending in ethanol in petrol or biodiesel in diesel, however it is likely that biofuels are blended into both the petrol and diesel fuels. In Member States with mandates on both overall as well as fuel-specific levels, fuel suppliers have less flexibility as they must comply with all imposed mandates.

The biofuel mandate threshold price, I_M, varies according to the penalty type, and it is calculated according to Eq. (3).

$$I_M = P \bullet (E_F - E_B) + I_F = P \bullet D_F + I_F = P + I_F \tag{3}$$

Equation (3) illustrates the relationship between biofuel price and associated emissions. For Member States with a GHG emission reduction mandate, a lower emission intensity increases the economic incentive for fuel suppliers to purchase biofuel to meet the blending mandate. By inserting the biofuel mandate threshold price calculated in Eq. (3) into Eq. (2) as I_B, it is possible to calculate the maximum price per liter of blended fuel (i.e., the highest potential price of the blend while complying with the mandate).

3 Results and Discussion

3.1 Mandates and Penalties

Figure 1 illustrates penalty levels compared to biofuel blending mandate fulfilment among EU countries. Per-unit based penalties range from below €1/MWh in Croatia to €25/MWh in Hungary, with an average of around €10/MWh (e.g., Czechia, Finland, and Luxembourg). For SAF blending mandates in France and Sweden, the implemented penalties that were slightly higher than their respective road transport penalties.

Figure 1 illustrate how most Member States fall short of meeting their biofuel blending mandates, regardless penalty type. No clear correlation emerges between penalty levels and mandate fulfilment, and while penalties may serve as a compliance mechanism, their effectiveness appears debatable. For example, Italy and Slovakia meet their mandates while imposing penalties of €5/MWh and €16/MWh, respectively, whereas Czechia does not despite a €10/MWh penalty. These cases suggest that while penalties may influence fuel supplier behaviour, they are not the sole determinant of mandate fulfilment. This pattern implies that moderate penalties paired with enabling conditions (e.g., sufficient fuel availability in relation to mandate size and economically viable pricing), may be sufficient to reach the mandates. Figure 1 demonstrate that many countries fulfil around 80–90% of their blending mandates, a few countries met 50% or less, while 11 Member States either meet or exceed their mandates. For countries close to fulfilling their mandates, the remaining gap may be bridged through nationally determined

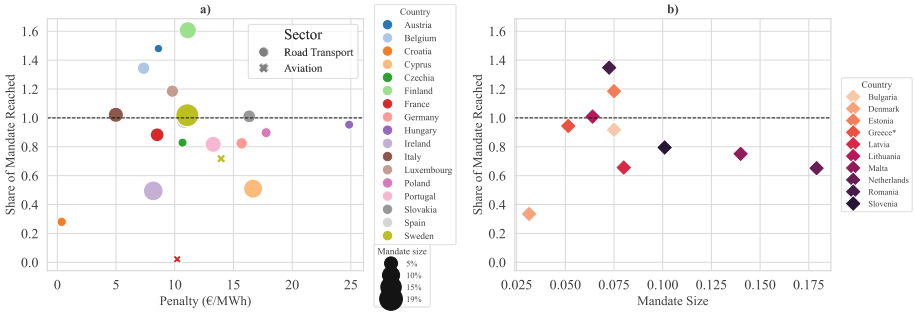


Fig. 1. Fulfilment of national biofuel blending mandates (y-axis) in EU countries in 2022. The horizontal line represents a fulfilled mandate. Fig. a) shows mandate fulfilment for road and aviation sectors in countries with per-unit based penalties, and b) for countries without per-unit based penalties. Greece is shown with 2021 data, since 2022 data was incomplete.

double-counting provisions (e.g., electricity in transport), although such measures were excluded from the study.

In the aviation sector, France and Sweden impose higher penalties compared to road transport, yet both fail to fulfil their SAF blending mandates. This further underscores that the penalty level alone does not guarantee mandate fulfilment. Figure 1a) depict how Sweden reaches 70% of its mandate, while France barely reaches 2%. This likely reflects the early-stage development of the SAF market, where limited supply and higher costs may hinder mandate compliance. In 2020, SAF accounted for less than 0.05% of total EU aviation fuel, with prices 1.5–6 times higher than conventional fossil fuel. Scaling production is therefore critical to reduce costs and meet the anticipated demand of 2.3 million tonnes in 2030 [18]. If SAF remains more expensive than the penalty cost, non-compliance may continue to be the economically rational option for fuel suppliers. Thus, while higher penalties could encourage mandate compliance, they must be accompanied by sufficient market support and fuel availability to be effective.

3.2 Blended Fuel Prices

The relationship between actual fuel prices and calculated maximum prices of blended fuel is visualised in Fig. 2. For road transport, darker bars demonstrate actual consumer prices without taxes, while lighter bars indicate calculated maximum blended fuel prices. Countries without per unit-based penalties were excluded from this analysis. For aviation, the calculated maximum blended fuel price is compared to the EU average aviation fuel price.

To further investigate the impact that biofuel mandates had on diesel fuel prices, a case study of the years 2018–2023 was performed for a few selected countries. Austria, Germany and Sweden were chosen because of the low price differences between calculated maximum prices and actual consumer prices in 2022. Finland was selected because of its large blending mandate, and France because of its low consumer prices. The results are illustrated in Fig. 3 which show the differences between calculated maximum blended fuel prices and actual market prices.

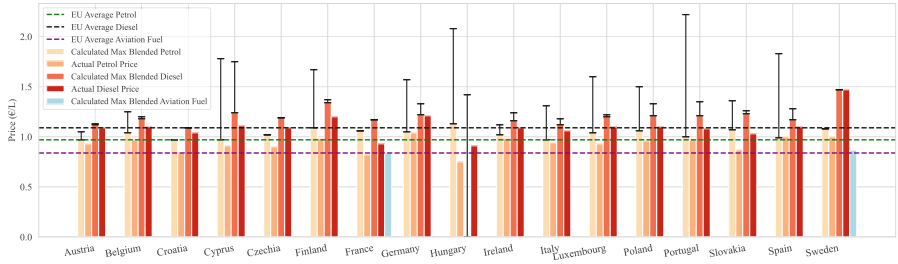


Fig. 2. Calculated maximum blended fuel prices (y-axis) for road transport and aviation fuel, excluding taxes, in EU countries (x-axis) in 2022. Hungary's diesel mandate was excluded due to insufficient data.

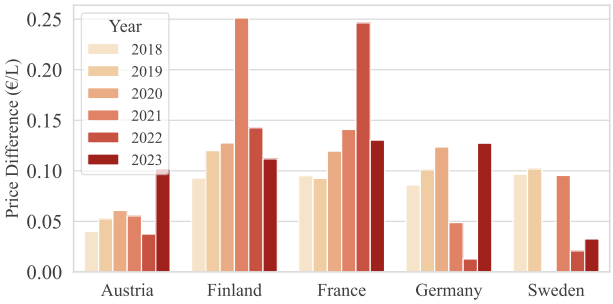


Fig. 3. Case study on price differences between consumer prices and calculated maximum fuel prices (y-axis), for the years 2018–2023 in selected Member States. Data for Sweden in 2020 was incomplete and therefore excluded.

In 2022, Swedish and German consumer diesel fuel prices were near their respective calculated maximum blended fuel prices, as demonstrated in Figs. 2 and 3. This indicates that fuel suppliers paid close to the biofuel mandate threshold price for the biofuel, suggesting that penalty levels might have set the biofuel market prices. Sweden recorded the highest consumer diesel price among all Member States, approximately 35% (€0.5/L) above the EU average diesel price. This implies a connection between penalty levels and consumer price levels. Both German and Swedish markets placed a premium on HVO compared to FAME due to its higher GHG mitigation potential, consistent with their GHG emission reduction mandates, as opposed to biofuel blending mandates based on volume or energy content. Given the limited supply of HVO in 2022, HVO suppliers had the opportunity to let national penalty levels determine fuel prices. In contrast, other markets could more easily adapt by increasing FAME shares or utilizing HVO produced from feedstocks not subject to the same upward price pressures. In such markets, the larger gap between actual fuel prices and the calculated maximum blended fuel prices indicates that penalties were not the binding price-setting mechanism. Instead, biofuel prices were shaped by broader market dynamics, reflecting greater flexibility and a more well-functioning market.

For the aviation sector, the calculated maximum blended aviation fuel price for Sweden and France was very close to the average EU aviation fuel price (see Fig. 2). This largely reflects the low SAF mandates in both countries, which meant that the SAF threshold price had a negligible impact on the blended fuel price. In practice, even if fuel suppliers had sourced SAF at, or just below, the threshold price, the impact on the final fuel price would have been minimal. However, since SAF was more expensive than the penalty cost, the mandates were not fulfilled in either country.

4 Conclusions

Focusing on 2022, a year of high fuel prices that prompted political action to reduce mandates and ease consumer costs, this study examines the biofuel market under stress and interactions between policy and market conditions. While this perspective provides valuable short-term insights, the narrow time frame limits our understanding of long-term policy-market dynamics. Nevertheless, the findings shed light on the role of national penalties in ensuring compliance with biofuel blending mandates across the EU.

The results indicate that while penalty levels can influence mandate compliance, no clear correlation emerges. Instead, mandate compliance might also depend on factors such as mandate size, enforcement of penalties, fuel availability and fuel supplier incentives. As seen in Germany and Sweden in 2022, when penalties are binding in markets with limited biofuel supply, they can become the price-setting mechanism for biofuels. This is an important factor to consider when deciding on penalty levels: in strained markets they can become price setting for biofuels, which in turn might impact final consumer prices. In contrast, the aviation sector highlights how immature markets limit penalty effectiveness: despite France and Sweden having implemented penalty systems, both countries fell short of their mandates. This was likely due to SAF prices being higher than the penalties, and that the SAF market remains underdeveloped.

Looking ahead, blending mandates are set to increase through 2030, alongside the introduction of sub-mandates for advanced biofuels and SAF. These create niche markets risking undersupply if new technologies are slow to commercialize. Against this backdrop, our findings highlight two key considerations for policymakers when setting penalty levels: 1) Penalties set too high risk driving up fuel prices during periods of supply constraints, 2) Penalties set too low risk making it economically rational for market actors to forgo compliance if biofuel production costs exceed the penalty.

To balance these two risks, policymakers should consider the potential cost profiles of the biofuels targeted by new mandates and conduct calculations similar to those in this study to assess the potential impact on consumer prices if the penalty becomes price-setting, and evaluate whether such price levels are acceptable.

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