Bioplastics and Biofuel Policy in the EU: Impacts and Interactions

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Introduction

Crude oil is sometimes referred to as "the blood of industrialization", and is a critical element supporting the development of the industrial age. This element is deeply embedded in the daily life of human beings. From foods and clothes to houses and transports, they all involve the use of crude oil. European Union (EU) is the second largest crude oil consumption region worldwide (IEA statistics[1]) with 45% of the total crude oil consumption being used to produce fuel while around 4 to 6% is used to produce plastics (PlasticsEurope 2017 Fact). This is equivalent to roughly 48 million barrels of oil per day according to the International Energy Agency (IEA) statistics. Since 86.7% of the European Union's (EU) crude oil consumption is imported (Eurostat statistics[2]), EU's oil supply is directly affected by shocks in world's oil production such as the oil crisis happened in the late 20th century which makes its energy supply insecure.

For this reason, the EU has a strong incentive to support the development of bioeconomy that provides an alternative product to substitute fossil fuel. The rationale behind the support of biofuel was stated in the 2012 Europe's Bioeconomy Strategy, which aims to reduce the dependency on nonrenewable sources and mitigate the pollution on the environment (European Commission, 2012). However, the main barriers preventing the efficient development of bioeconomy identified by the Commission are the insufficient links between policymakers and bioeconomy stakeholders, and the insufficient links between policies related to the bioeconomy (European Commission, 2012, p.22). Hence, there is a need for better understanding of different policy impacts on the bio-based markets and appropriate ways to promote their development.

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[1] https://www.iea.org/geco/data/

[2] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Oil_and_petroleum_products_-_a_statistical_overview&oldid=404136#Imports_of_crude_oil

1.1 Biofuel policy and its impact

The second oil crisis in 1979 caused by the outbreak of the Iran-Iraq War evoked the panic of a crude oil shortage. Even though the global oil supply only dropped by 4%, many people start queuing at the fuel stations to purchase fuels which led to even higher fuel prices on a global scale. This event revealed to the EU government a tip of the iceberg of what could happen in the case of an oil supply shortage. As a consequence, biofuel starts gaining its popularity after the oil crisis as it performs the same function as fossil fuel and it can reduce the level of dependence on fossil fuel. The first generation biofuel is fuel produced from food crops, such as rapeseeds for biodiesel and wheat for bioethanol. These bio-products are chemically identical to its fossil-based references. Advancements in technology that can increase crop yield and extraction rate enhanced the potentiality of biofuel to replace its fossil-based references. Biofuel not only improves energy security in the EU but also contributes to reducing greenhouse gas (GHG) emissions (Mathews, 2008). This is because the amount of carbon released to the environment though biofuel combustion is equal to the amount of carbon contains within the plant. Hence some people referred to it as carbon neutral. Despite its contribution to GHG emission, biofuel is suffering on increasing its market demand due to a relatively expensive production cost comparing to costs associated with the production of conventional fuel. For this reason, in order to promote biofuel consumption and production, the policymakers devised the following biofuel policies (ePURE PPT, Rossi & Cadoni, 2012): (i) Mandatory target (mandate), (ii) Tax incentives (tax credit / tax exemption), and (iii) Double counting, which means awarding double amounts of tradable certificates to certify the volume of recycled biomass used to produce biofuel, eg. Renewable Transport Fuel Certificates (RTFC) for the UK and Italian Bio Certificates.

Table 1

Country[3]	**Biofuel policy**	**Double counting**
Germany	Blend mandate based on GHG saving after 2014	No
France	Blend mandate	Yes
Italy	Blend mandate	Yes
Spain	Blend mandate	No
United Kingdom	Blend mandate	Yes
Sweden	Tax exemption (Zero tax until 2016)	Not applicable
Netherlands	Blend mandate	Yes
Finland	Blend mandate	Yes
Belgium	Blend mandate	Yes

Source: USDA "Biofuel Mandates in the EU by Member State in 2017"

The majority of member states in the EU adopt a fuel blend mandate. The role of a blend mandate is to assign obligations to the producer to blend a certain amount of bio-based feedstock with fossil fuel when producing it. The history of biofuel policy in the EU can be traced back to the late 1990s where the case of biofuel was put forward for discussion. The first official biofuel policy, Biofuels Directive 2003/30 EC, passed in 2003 with the European Commission promoting biofuel consumption through voluntary mandates and tax credits. It provides the first indicative biofuel target for the EU. This support was further developed in 2009 when EU Renewable Energy Directive (RED) announced the Directive 2009/28 EC, which oblige each member state to formulate policies to ensure that 10% of total transport energy comes from

[3] Selected based on Nova map 2017 number of biorefinery plants within the country is greater than 5.

renewable sources by 2020. As a result, EU Member States increased the blend mandate and imposed an obligatory target for biofuel consumption. However, rising concern about food-fuel competition led to a review of this policy in 2012 with the European Commission suggesting to limit biofuels produced from food crops such as rapeseed, wheat and sugar beet to 5% of total transport fuels. In mid-2015, the EU confirms a cap of 7% for first-generation biofuel[4] (biofuel from food crop) consumption due to their negative impact on food security (Skogstad, 2017).

Many studies had estimated the environmental impact of biofuel in different dimensions such as energy efficiency, land preservation, and greenhouse gas (GHG) emission. Biodiesel has a positive fossil energy ratio[5] as on average 90% of its feedstock is renewable (Gadonneix et al., 2010 Pg.80). Bioethanol, also known as alcohol, is made by fermenting any biomass with a high content of carbohydrates through a process similar to beer brewing, thus it is completely renewable. Biofuel also helps to reduce GHG emission as it is essentially carbon neutral meaning that the amount of carbon emitted from burning biofuel is equivalent to the amount of carbon absorbed by the crop (Ji & Long, 2016).

Studies on biofuel policy mainly focus on investigating the impact of biofuel policy on food security, rural development and GHG emission. Researchers answered these questions mainly focusing on how biofuel policy can affect food prices, land use, and farmer's income. Doumax-Tagliavini et al. (2016) employed a recursive dynamic computable general equilibrium model to analyze whether a higher tax on fossil fuel will help to promote biofuel and economic development in rural areas by testing two different scenarios. In the first scenario, a higher tax on

[4] First generation biofuels are generally made from sugars, grains or seeds. Since the feedstock used to produce it can be alternatively used for food and feed, it may intensify the competition between fuel and food if we produce more first generation biofuel.

[5] Fossil energy ratio = Fuel energy/Fossil energy inputs

fossil fuel was employed. Their result showed that additional tax on fossil fuel will help to reach the 7% target for crop-based biofuel. However, this policy could cause a recession in the biofuel sector followed by a larger decrease in fossil fuel consumption. In scenario two, they made a first attempt to measure the policy impact on second-generation biofuel[6]. They found that an increase in fixed tax on fossil fuel was not significant to help the EU reach its advanced biofuel target. They suggested that alternative policy instruments should be implemented after careful consideration depending on the policy priorities, environmental gains or economic gains. Furthermore, their result did not find any evidence that a rise in biofuel price can cause a rise in food price. Gardebroek et al. (2017) investigate how biofuel policy can impact crop price, specifically rapeseed, the major feedstock used for biodiesel production in Europe. They also analyzed the change in land use caused by a change in crop price. Their empirical result shows that biofuel policy in Germany and France does not have an impact on rapeseed prices, despite in theory there is an upward impact.

The reverse policy introduced in 2015 evoked a stream of studies focusing on the impact of abolishing biofuel policy applying mainly computable general equilibrium (CGE) models. Deppermann (2016) studied the effect of abolishing first-generation biofuel policies on farm income in Germany using ESIM[7] and FARMIS[8] models and disaggregated German farm data. His result revealed that on average there was a negative impact on agricultural income. In addition, Delzeit et al. (2018) compared how different policy instruments can help in reducing

[6] Second generation biofuels are generally made from lignocellulose biomass. Since its initiate intention is to avoid fuel-food competition, its feedstock is either produced from non-food crops and residuals such as corn stalks, rice husks, trees and grass or grown on marginal arable croplands. URL: https://sim.sbio.vt.edu/?p=2341

[7] European Simulation Model (ESIM) is a partial equilibrium multi-country model of agricultural production and consumption.

[8] FARMIS is a comparative-static programming model for farm groups based on information from the farm accountancy data network (FADN). URL: https://www.thuenen.de/en/infrastructure/the-thuenen-modelling-network/models/farmis/

the land use competition. They utilized a CGE model, DART-BIO[9], to analyze whether land use competition will decrease if we abolish biofuel policy or introduce a tax on meat and dairy consumption. They found that a tax on meat and dairy consumption had a larger impact on reducing land use competition than abolishing biofuel policy. On top of that, they found using policy instruments such as tax that it was more efficient changing consumer behaviors than changing the preference of the consumer. Finally, Enciso et al. (2017) applied Aglink–Cosimo[10], a global economic model covering the main agricultural traded commodities, to study the impact of abolishing biofuel policy on biofuel production. Their forecast showed a 25% decrease in ethanol and a 32% decrease in biodiesel. However, this reduction only caused a moderate decrease in the price of feedstock. Hence, they concluded that abolishing biofuel policies would not necessarily lead to more food security.

1.2 Bioplastic policy and its impact

A study done by Philp (2015) points out that unlike biofuel and bioenergy, bio-based materials such as biochemical and bioplastic have not received much attention with most support being only provided for R&D. Currently, bioplastic only represents around 0.5% to 1% of EU annual plastic consumption (European Commission, 2018, footnote 53). This proves the limited market support for bioplastic. However, in 2015, French legislation aimed to promote bioplastics in order to comply with the 2012 European Bioeconomy Strategy of reducing GHG emissions and dependence on non-renewable and unsustainable resources. This legislation, in large part,

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[9] Dynamic Applied Regional Trade Model (DART) was designed to analyze long-term future trends. DART-BIO has been developed especially for analyzing global land use change and biofuel policies. URL: https://www.ifw-kiel.de/institute/research-consulting-units/the-environment-and-natural-resources/articles/dynamic-applied-regional-trade-model-dart/

[10] The Aglink-Cosimo modelling system is a comprehensive partial equilibrium model for global agriculture. URL: http://www.agri-outlook.org/about/

resembles the biofuel blend mandate as it requires single-use bags to contain a minimum bio-based content. It starts from a minimum of 30% bio-based content in the single-use plastic bags after January 1st, 2017 to 40% after 2018 and it further rises to 50% after 2020. This mandate is finally planned to reach 60% after 2025. The question that arises here is whether this rapid expansion of bioplastic can help us move towards the sustainable development goal such as reduce dependency on nonrenewable resources and mitigating environmental pollution.

There are only a few studies that attempt to answer the question above. Escobar (2018) employed a CGE model, GTAP[11], to assess the economic and environmental impact of increased bioplastic shares in total plastic consumption. He disaggregated the plastic sector into conventional plastic and bioplastic sectors in GTAP 9 database and simulated two hypothetical scenarios. In scenario 1, he applied subsidies for bioplastic revealing that the subsidies can reduce the market price for plastic and hence increase its demand. In scenario 2, taxes for conventional plastic were applied in the market and resulted in increased plastic prices and falling demand for plastic at the worldwide level. As a result, the GDP growth rate of the main plastic production countries such as US, Europe, and China will slow down. Furthermore, expanding the bioplastic share of the total plastic consumption doesn't necessarily lead to a more sustainable society, as producing the first generation bio-based plastics will increase food consumption while reducing total plastic consumption and lower GDP, which will lead to higher food price and higher unemployment, respectively. Thus, the author suggested that recycling plastic should be the main target. However, regardless of food-fuel competition and plastic recycling problem, bioplastic provides

[11] Global Trade Analysis Project (GTAP) is a multiregional, multisectoral, computable general equilibrium model, with perfect competition and constant returns to scale. URL: https://www.gtap.agecon.purdue.edu/models/current.asp

a higher environmental gain compared to biofuel in terms of saving GHG emission and fossil energy (Alvarenga and Dewulf, 2013).

1.3 Fuel and plastic relationship

The main feedstock for fuel and plastic is petroleum with the fuel and plastic supply chains being integrated (CIEL report, 2018). The emerging bioeconomy introduces an alternative feedstock, bioethanol, for both fuel and plastic products with both of them now produced from either petroleum, bioethanol or a mixture of both. Biofuel and bioplastic products are chemically identical to fossil-based fuel and plastic, however, they have a relatively low carbon footprint. Alvarenga and Dewulf (2013) performed an attributional life cycle assessment on an equal amount of ethanol used as fuel and plastic. Their results showed that the ethanol used to produce plastic saved 32.0 MJ of fossil energy and 1.87 kg CO2eq where the ethanol used to produce fuel saved 27.2 MJ of fossil energy and 1.82 kg CO2eq. Hence, people see ethanol as a silver bullet to solve the environmental issue.

However, a well-known obstacle for bioethanol production is its uncompetitive cost against its fossil counterparts. In order to overcome this obstacle, Eerhart et al. (2015) suggested that a large scale production is required. Hence, it is optimal for bioethanol producer to supply not only fuel but also plastic. Any policy instruments that can increase bioethanol demand will help bioethanol producer to become competitive against its fossil-based counterpart.

In addition, multiple policies had been implemented in recent years to tackle environmental issues. This invokes a stream of studies analyzing the interaction effects of multiple policies. Fischer and Preonas (2010) conducted a study that investigates optimal policy choice in the presence of overlapping renewable energy policies. They concluded that optimal policy combination should depend on the policy goals and market failure. If the goal is to raise renewable energy share, a mandate can achieve the target efficiently. De Gorter and Just (2009) studied the impact of a blend mandate and tax credit on biofuel quantity and price. A mandate itself can increase the fuel price and hence reduce the fuel consumption. Since the fuel producer is required to mix a certain amount of bioethanol with fossil fuel, this policy also contributes to reducing the GHG emission and the dependency on fossil fuel. Tax credit on bioethanol can also promote bioethanol production in as much as bioethanol price becomes more competitive. However, the market price of biofuel will rise by a smaller margin compared to a mandate. Hence, its contribution to GHG emission and dependency on fossil fuel is lower than a mandate. The effect of these two types of policy can also be found in the energy market. Fischer (2009) provided a theoretical model explaining the impact of subsidy or tax on energy market price. A subsidy will lower the consumer price where a tax will do the opposite. This impact was then compared with the impact of a "Renewable Portfolio Standard (RPS)", which is known as renewable obligations and green certificates that require either producers or users to derive a certain percentage of their electricity from renewable sources. RPS functions exactly the same as the biofuel blend mandate. The result they found was similar to those in De Gorter and Just (2009).

The most important message derived from De Gorter and Just (2009) is the abnormal result when simultaneously imposing a blend mandate and a tax credit. Initially, both policies had a positive impact on GHG emission and fossil fuel dependency, anticipating to enhance each other’s effect. However, this is not the case. De Gorter and Just found that the interaction of these two policies actually created a perverse effect on GHG emission and fossil fuel dependency. The price of fuel increased but the fuel consumption also increased. This is because a mandate in place already boosts up the bioethanol production and the price of biofuel also increases leading to reduced fuel consumption. The introduction of a tax credit will lower the margin of price increase effect from the mandate. As a result, the reduction in fuel consumption will be smaller. They believed under that situation, part of the tax credit was used to substitute fossil fuel price.

The scope of this paper is to provide a better understanding of the impacts of policy instruments on bio-based products and make appropriate suggestions on how to accelerate the growth of the bio-based economy. We analyze the effectiveness of policy instruments on promoting the transition from a fossil-based to a bio-based economy using the fuel and plastics markets. More specifically, we focus on two bio-based products, biofuel and bioplastic. Any fuel blended with bio-based feedstock is classified as biofuel and can further divide into bioethanol and biodiesel (Gadonneix et al., 2010 Pg.65). Biofuel can refer to biodiesel and bioethanol, we are particularly interested in bioethanol because of two reasons. First, the production cost of bioethanol is relatively lower than the biodiesel (Festel, 2008), and second, bioethanol has a wider application than biodiesel. In addition, while bioethanol and biodiesel can be both used as fuel, only bioethanol can be used to produce bioplastics. The bioplastics referred here are plastics produced either partially or wholly from biomass with both biodegradable and non-biodegradable bioplastics being included.

This following sections of this paper will be organized as follows. Section 2 will describe the details of the tractable partial equilibrium model and the algorithms used to derive our results. Section 3 presents the data we used for calculating our result and the methods we used to gather these data. Section 4 presents the counter-intuitive results under different policy scenarios. And the last section provides some remarks based on our results.

2. Methodology – Model of EU biofuel and bioplastic market

Bioethanol, also known as alcohol, can be used to produce fuel, chemicals, food and beverages. In the EU, the main feedstock for bioethanol is sugar beet, wheat, and maize. They account for over 90% of the feedstock used in bioethanol production. The bioethanol that is used to produce food and alcoholic beverages is subject to a high tax, which produces a considerable tax revenue for the government. In contrast, industrial use of bioethanol has relatively low tax duty. To distinguish bioethanol for industrial-use from bioethanol for food and beverage production, the first one is called denatured ethanol while the latter one is called undenatured ethanol. Denatured ethanol usually mixed with different types of chemicals depending on its end use. This process is irreversible which means when the ethanol becomes denatured, it can only be used in industrial production.

The model used in this paper focuses only on bioethanol used to produce fuel and chemicals. Since the production cost of bioethanol is relatively higher than its fossil-based reference, we assume that the production of bioethanol is mainly driven by incentive policies introduced by the government. Currently, more than 90% of ethanol is converted to industrial ethanol, where 81% consumed by fuel market and 10% consumed by the chemical market (PlasticsEurope 2017 Fact). As a large portion of bioethanol is used to produce fuel, incentive policies on promoting bioplastic production need to be installed. With the introduction of bioplastics, the bioethanol market is now divided into three shares: fuel, plastic and other chemicals.

The research methodology for our analysis is based on the rationale that incentive policies can be applied not only in the fuel market but also in other markets. Based on this rationale, we expand the single market equilibrium model in De Gorter and Just (2009) to multiple markets to depict the broader picture and interaction effects between two markets and policies. We build a tractable partial equilibrium model to evaluate the policy impacts of different bioeconomy incentives. Our model will focus on four different markets: bioethanol market, fuel market, plastic market, and crude oil market. We assume the fossil-based segment and bio-based segment for fuel market and plastic market are separated by the blend mandate policy. This means that the blend mandate fully determines the portion of bio-based material used in the market. The reason behind this is that ethanol's market price is relatively expensive comparing to the price of crude oil. Thus, if no mandate in place, producer will select the cheaper option, crude oil.

Crude oil market

The supply of crude oil is estimated from the following equation:

$$(1) \qquad S_O = (1 - M_F)D_F + (1 - M_P)D_P$$

where S_O, D_F and D_P denote the supply of crude oil, demand of fuel and demand of plastic, respectively. M_F and M_P denote the blend mandates for fuel and plastic. Subtracting the blend mandate from the total demand of fuel and plastic give us the fossil-based portion of fuel and plastic demand. Equation (1) shows the supply of crude oil only depends on the fossil-based portion of fuel and plastic.

Bioethanol market

Since we assume the only feedstock for fuel and plastic production were crude oil and ethanol. The ethanol supply is determined from the following equation:

$$(2) \qquad S_E(P_E) = M_F D_F(P_F) + M_P D_P(P_P)$$

where S_E denotes the supply of ethanol. We assume the supply and demand quantity are determined from its own price. P_E, P_F and P_P present the market price for ethanol, plastic, and fuel, respectively. The sum of Equations (1) and (2) gives us the total demand for fuel and plastic in the economy.

$$(3) \qquad D_F(P_F) + D_P(P_P) = S_O(P_O) + S_E(P_E)$$

Supply of crude oil is also determined by its own price, P_O. Equation (3) represents the market clearing equilibrium. Together with Equation (2), they form the constraint of our model that is the supply of ethanol and the supply of feedstock[12] cannot be less than its demand.

$$(4) \qquad S_E(P_E) \geq M_F D_F(P_F) + M_P D_P(P_P)$$

$$(5) \qquad D_F(P_F) + D_P(P_P) \leq S_O(P_O) + S_E(P_E)$$

Fuel market

Our focus is to estimate the market price of fuel, plastic, ethanol and crude oil from our model after a shock. If there is a blend mandate implemented in the fuel market, the price of the fuel P_F, will be the weighted average of ethanol and crude oil price.

$$(6) \qquad P_F = M_F(P_E) + (1 - M_F)(P_O)$$

[12] By adding up crude oil supply and ethanol supply.

Plastic market

Similar to the fuel market, the price of plastic, P_P, is also the weighted average of crude oil and ethanol price with t_P denoting the tax credit for plastic. It changes the price of plastic at the rate of the multiplication of the plastic mandate and the tax credit, $M_P t_P$.

$$(7) \qquad P_P = M_P(P_E - t_P) + (1 - M_P)(P_O)$$

This methodological framework enables us to quantify the impact of both blend mandate and tax credit on the market equilibrium for fuel and plastic. We shock the model in various situations to simulate the effects of the implementation of various policies to reveal the magnitude of the impact and the interaction effect of the biofuel and bioplastic policies.

3. Data and Calibration

We calibrated the model to EU fuel and plastic market. Data for calibration include the price for all markets, their supply and demand elasticity and the relevant quantities. These values were derived from various sources. We assume the supply of ethanol is equal to its own consumption, which was 5.25 billion litres in 2017 according to ePURE key figures 2017. 81% of ethanol was for fuel use and this was equivalent to 4.25 billion litres. We assume this amount is equivalent to 5% bio-based material used in fuel based on the ePURE report (2018). The report stated that although the target for renewable energy shares in transport (RES-T) is 10%, bioethanol used in fuel only reach about half of its target. The crude oil supply for fuel was calculated by dividing the ethanol quantity with the percentage of bio-based material.

The share of bio-based material used in plastic was estimated based on EC (2018) “A European Strategy for Plastics in a Circular Economy” document where it states “bioplastic represent between 0.5 and 1 % of EU annual plastic consumption". This percentage multiplied with the plastic demand stated in PlasticsEurope (2017) which was 49.9 million tonnes gives us an average of 0.37 million tonnes of bioplastic consumed in 2017. And, we assume the ethanol to plastic conversion rate is the same as crude oil to plastic conversion rate. So, the supply of ethanol is equal to 72% of bioplastic quantity (Gervet, 2017). We divide the bio-based material percentage with the supply of ethanol for plastic, which gives us the total amount of plastic feedstock needed. From there we subtracted the ethanol feedstock from the total amount of feedstock and that gives us the crude oil supply for plastic.

We harmonize all units to billion litres using the conversion rate in BP statistics review (2018) and the values used in our calibrated model are listed in Table 2. The price elasticity and the zero profit market price of crude oil, ethanol, fuel and plastics were adopted from different studies, which are also listed in the table.

Table 2

Parameter/variable	**Value**	**Units**	**Source**
Crude oil supply for fuel	80.7975	Billion litres	Author calculation
Crude oil supply for plastic	41.5421991	Billion litres	Author calculation
Ethanol supply for fuel	4.25	Billion litres	ePURE key figures 2017
Ethanol supply for plastic	0.3139209	Billion litres	PlasticsEurope 2017
Total crude oil supply	122.3397	Billion litres	Author calculation
Total ethanol supply	4.5664	Billion litres	Author calculation
Fuel demand	85.05	Billion litres	Author calculation
Plastic demand	41.8561	Billion litres	Author calculation

Crude oil supply elasticity	0.128		IMF report 2018
Ethanol supply elasticity	2.2		De Gorter and Just 2009
Fuel demand elasticity	1.81		De Gorter and Just 2009
Plastic demand elasticity	-2.35		Muraleedharan et al. 2007
Price for fossil-based feedstock	1.25	Euro / litres	Festel 2008
Price for bio-based feedstock	1.41	Euro / litres	Festel 2008
Price for blended fuel	1.258	Euro / litres	Author calculation
Price for blended plastic	1.2512	Euro / kg	Author calculation
Bio-based material in fuel	5	%	Author calculation
Bio-based material in plastic	0.75	%	Author calculation

We adopted the assumption from Festel (2008) that the oil price is US$60 per barrel and the price for fossil-based feedstock costs €1.30 per litres at the petrol station. The price for fossil-based feedstock includes €0.05 euro/litres marginal profit (Festel, 2008), which we later subtracted from the petrol station price. This gives us the price shown in Table 2. The bio-based feedstock has a marginal profit of €-0.11 euro/litres. Hence, the price for the bio-based feedstock is €1.41 euro/litres. The price for blended fuel was calculated by substituting the price for fossil-based and bio-based feedstock into Equation (6). The price for blended plastic was calculated using the same technique but the price for fossil-based and bio-based feedstock was substituted into equation 7 instead. We adopted the conversion ratio of 1 for kg and litre. Hence, the price of fuel and plastic can be comparable.

4. Results

In this section, we simulate five different scenarios by applying different shocks to the EU fuel and plastic market. These shocks include applying blend mandate and tax credit for the two markets and adjusting their levels (Table 3). Our focus is the impact of these shocks on the market price and quantity. We first simulate the scenario where there is only mandate in the fuel market at 5%. Then, we introduce a mandate in the plastic market with a 5% fuel blend already in place. Next, we let both fuel and plastic mandates increase simultaneously. For the fuel mandate, it has been increased from 5% to 20%; for the plastic mandate, it increased from 0.75% to 15%. After that, we introduce a tax credit for the bio-based material in the plastic market where the blend mandate for fuel is 5% and for plastic is 0.75%. At last, we assume there are 10% fuel mandate and 30% plastic mandate in the market and we introduce plastic tax credit and analyze their impacts and interactions.

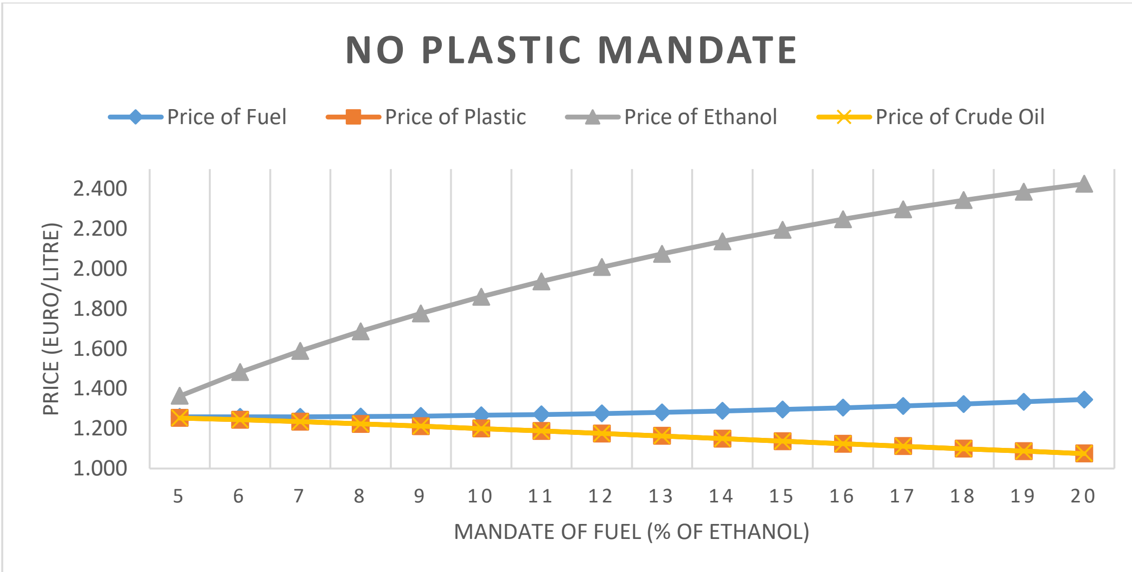
Table 3

	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**		**Scenario 5**	
	Blend mandate	Tax credit	Blend mandate	Tax credit	Blend mandate	Tax credit	Blend mandate	Tax credit	Blend mandate	Tax credit
Fuel Market	5-20%	0	5%	0	5-20%	0	5%	0	10%	0
Plastic market	0	0	0.75-15%	0	0.75-15%	0	0.75%	€0.1-1	30%	€0.1-1

In scenario, there is no mandate in the plastic market, while the mandate for fuel gradually increases from 5% to 20%. Figure 1 depicts the trend of the price change regarding the increasing blend mandate. There are four curves in the graph but you can only saw three of them because the price of plastic is now equal to the price of crude oil. An increase in fuel mandate drives up the demand for ethanol, which is revealed by the increasing trend of ethanol price. However, this higher ethanol price can be associated with a larger quantity of supply. This increase in the ethanol quantity makes up the difference in the decreasing supply of crude oil since its price decreases. On the demand side, the price of fuel increases and its demand quantity will decrease as higher selling price usually leads to lower demand in competitive markets. This result is in line with the results from de Gorter and Just (2009). However, the interesting part is the price of plastic. Since there is no mandate in the plastic market, all plastic is produced using crude oil rather than the more expensive ethanol. As a result, the price of plastic also decreases leading to a higher consumption of plastic consumption solely driven by the crude oil market dynamics.

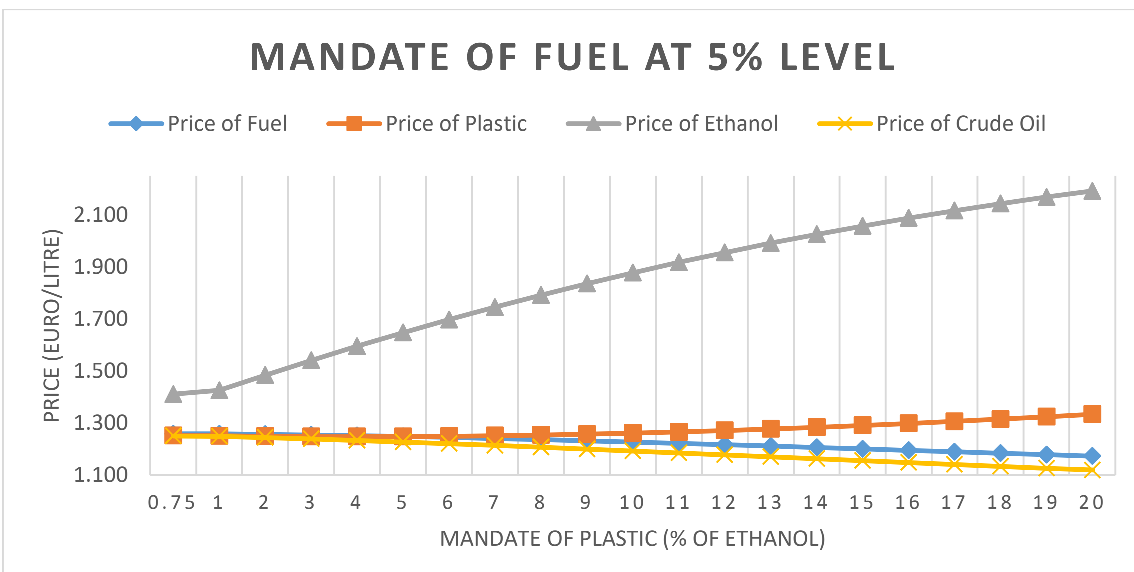
In the second scenario, a plastic mandate is added into the simulation anticipating to expand the demand for ethanol. Hence, its effects on crude oil and ethanol price are similar to the output of scenario 1 where the ethanol price rises and crude oil price falls. We initially expect to have a positive change in the prices of fuel and plastic moving in the same direction. However, the result shows that the price of fuel decreases while the mandate in the plastic market increases, while the price of plastic decreases first and then increases. It hits its turning point when the plastic mandate equals to fuel mandate. We believe the reason that causes this result is the market size differences of crude oil and ethanol. The decrease of crude oil price dominates the price decrease in the fuel and plastic market.

Figure 1: Scenario 1



Source: Own calculation

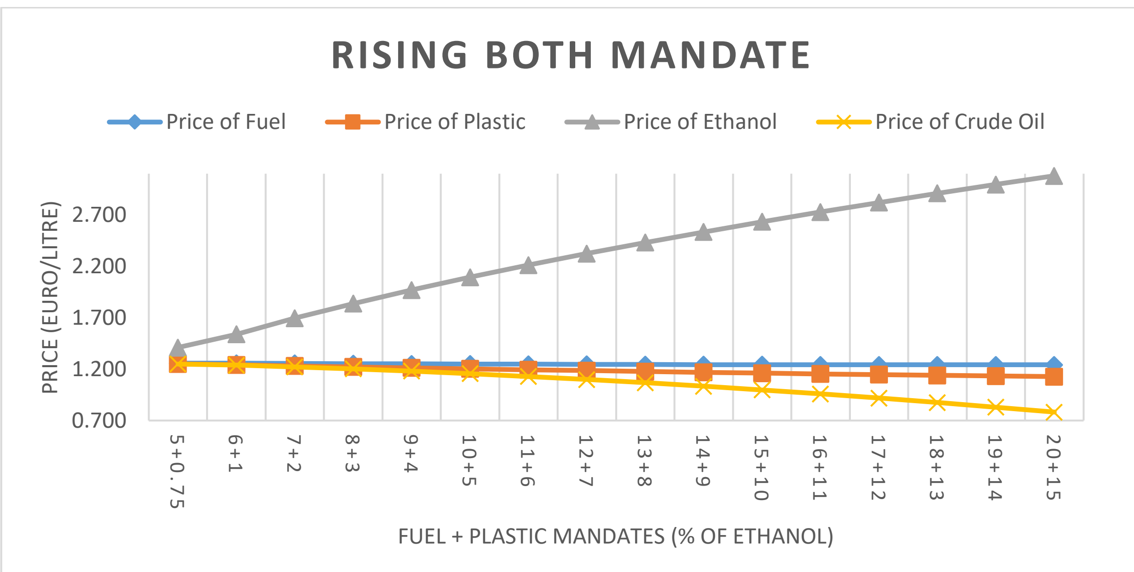
Figure 2: Scenario 2



Source: Own calculation

For scenario three, increasing the blend mandate for both markets further revealed the dominating effect of crude oil price change. Ethanol price increases and crude oil price decreases when a higher mandate in both markets is applied. Under this scenario where both mandates rise, the price of fuel and plastic move in the same direction. We expect they will both increase since, in a single market, the mandate obliges the producer to produce with the relative expensive ethanol. This effect is revealed in the first scenario where no plastic mandate was involved. However, when both fuel and plastic mandates exist, we can observe a slight decrease in the prices of both fuel and plastic markets.

<u>Figure 3: Scenario 3</u>

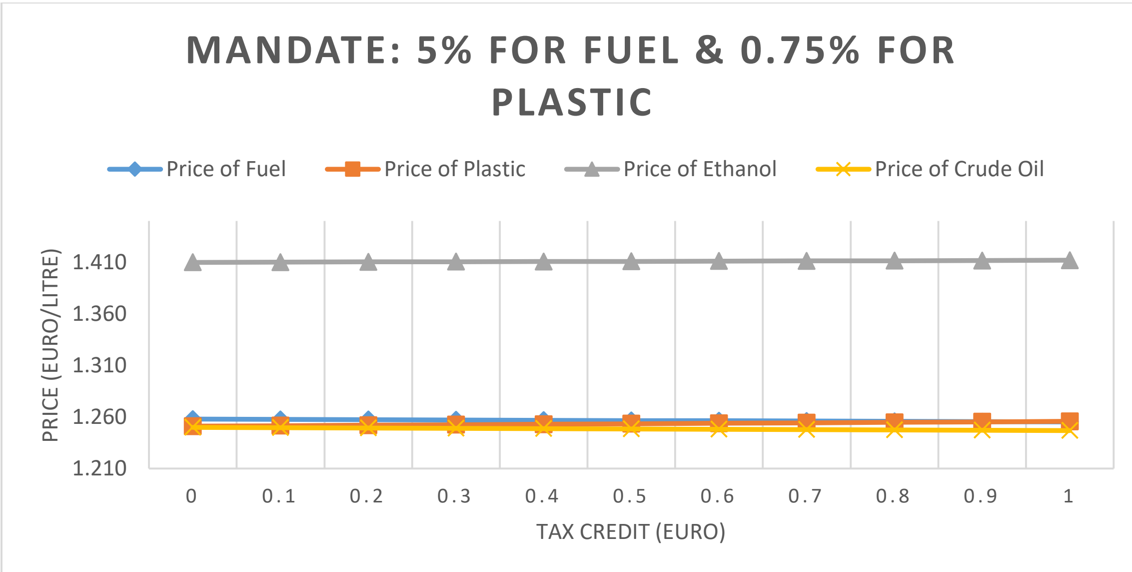


Source: Own calculation

Tax on plastic is very common among countries nowadays. Some countries apply taxes on all plastics undistinguishing, while others excluded bioplastic from the levy. This exemption can be viewed as a tax credit for bioplastic, which motivates us to simulate a scenario where there is a tax credit applied to the market. In scenario four, we simulate the market with a tax credit at the situation where the mandate for fuel market is 5% and for plastic market is 0.75%. We then increase this level to 10% according to the EU RES-T target and 30% for plastic market according to the French plastic blend policy (scenario 5).

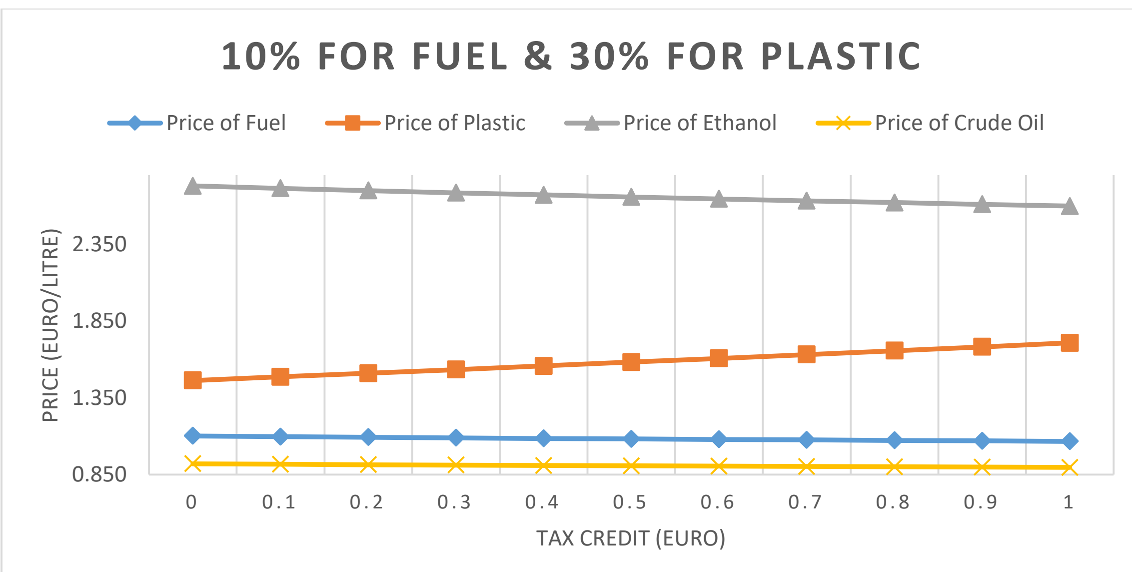
The market prices change differently in these two last scenarios. In scenario 4 with a lower blend mandate in both markets, the price of ethanol increased slightly but the price of crude oil is decreased along an increasing the tax credit. However, in the higher blend mandate situation, the price of ethanol changes in the opposite direction. Both the ethanol and crude oil price decreased along an increasing tax credit. We believe the reason that causes this result is the difference of mandate level. In the first situation, the fuel market used 5% bio-based material which is higher than the plastic market. A tax credit for plastic market helps to promote ethanol used in the plastic market. Thus, the price of ethanol increased. However, in the second situation, the mandate for the fuel market is only 10% which is lower than the plastic mandate. Hence, a tax credit on the plastic market will create an adverse effect which subsidising crude oil price and leads to a lower ethanol price.

Figure 4: Scenario 4



Source: Own calculation

Figure 5: Scenario 5



Source: Own calculation

5. Discussion and conclusion

This paper has revealed some interesting results on the interaction of fuel and plastic markets under different bioeconomy policies such as blend mandate and tax credit. It brings out a few important messages. First, applying a mandate on one market does increase bio-based material consumption but at the same time it increases fossil-based material consumption in the other market if the other market also uses the same feedstock. For this reason, there is a need to apply blend mandates on both markets in order to decrease the fossil-based consumption. In addition, the crude only consumption only reduced slightly while ethanol consumption increased rapidly. Second, applying tax credit on the market with a mandate creates a perverse effect only if the market has a larger mandate compared to other markets. For example, when plastic market has 30% blend mandate, an addition tax credit for plastic will lower ethanol supply and increase plastic consumption.

This study emphasized on the qualitative results rather than on the quantitative ones, since the analysis abstracts the complexity of the production chain of all the markets. Other elements, such as international trade, cost function and the variety of the plastic market might have an impact on the market price and quantity. Future studies can model the production chain in a more holistic way in order to see how the policy impact passes along the production chain to the consumers, while this is the first attempt to analyse the interactions of fuel and plastic with a new feedstock being introduced by bioeconomy. This study hopes to shed some light on the EU regulation framework of these two markets and help to move towards sustainable development in EU.

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