

The interconnections between Fossil Fuel Subsidy Reforms and biofuels

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Abstract

Albeit not without some controversy, mandates like the Renewable Energy Directive (RED) aim to increase biofuel consumption to reduce greenhouse gas emissions (GHG) in the transport fuel sector (Britz & Hertel, 2011). At the same time, Fossil Fuel Subsidy Reforms (FFSR) to support governments' climate objectives are gaining traction in the political sphere, such as in the European Union, where it is explicitly mentioned in the 'Green Deal'. These two fuel types are known to interact through price mechanisms (Delzeit et al. 2021c; Winchester & Ledvina, 2017), but the impact of fossil fuels and biofuels policies on one another remains to be investigated. Using the DART-BIO model, a Computable General Equilibrium (CGE) model, we study how phasing out fossil fuel consumption subsidies and biofuel mandates would impact one another.

We find that where both policies are implemented they can have a positive additive effect. For example, a FFSR can support the achievement of biofuel consumption targets at lower costs when it is implemented in the same region. If the FFSR occurs abroad however, it can have a detrimental impact on the biofuel target through a leakage effect. We estimate that the EU would need to spend USD 2 billion more on biofuel subsidies to meet the maximum allowable biofuel target of RED, given that the rest of the world phases-out subsidies but the EU does not. Through their impact on the global market, biofuel subsidies can also lead to leakages. A region that implements neither policy would experience an increase in its consumption of fossil fuels and decrease in its consumption of biofuels as a result of each policy being implemented abroad. In conclusion, while the policies can have a positive additive effect, they also lead to leakages that are detrimental to the overall goal of reducing GHG emissions that they aim to achieve.

1. Introduction:

The first significant push for the production and consumption of biofuels began in the 1970s as a way to reduce dependence on imported oil following the oil embargo imposed by the Organization of the Petroleum Exporting Countries on countries like the USA (UNCTAD, 2009). More recently, biofuels that sequester carbon through the growth of feedstocks became part of governments' renewable energy strategies to reduce Greenhouse Gas (GHG) emissions (Calzadilla, A. et al. 2016). Notable examples include the European Union's Renewable Energy Directive (RED) implemented in 2003 and the United States' Renewable Fuel Standard (RFS) created under the Energy Policy Act of 2005 (EPAct).

A major challenge to climate mitigation from the transition to a bio-economy is the reduction of fossil fuel resources and their replacement with renewable biomass (Delzeit et al. 2021c). Biofuels have been

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found to be sensitive to changes in the price of their fossil fuel substitute (Winchester & Ledvina, 2017). Fossil Fuel Subsidies (FFS) that artificially distort the price of fossil fuel subsidies however remain large (UNEP, OECD, IISD, 2019). Global pre-tax FFS were estimated at \$269 billion in 2016 (Coady et al. 2019), and \$450 billion in 2020 (Parry et al, 2021). In the EU alone, the European Commission estimated that in the EU they equal €52 billion³ in 2020. Yet, phasing out these Environmentally Harmful Subsidies (EHS) has consistently been found to support the deployment of low-carbon technologies (Bridle and Kitson, 2014; Zinecker et al., 2018; International Energy Agency, 2014) and to be a key policy to reach the target set by the Paris Agreement (Lin and Jiang, 2011; McFarland and Whitley, 2014).

The implementation of FFS is often aimed at improving or ensuring access to and affordability of energy by keeping prices low for vulnerable households. FFS were however found to be a costly approach to do this due to the substantial leakage of their benefit to high-income groups (Granado et al., 2012). They also fail to improve affordability or access to energy for households that live outside of the reach of infrastructures and distribution networks (Zinecker et al., 2018). And arguably worse, they divert resources from sectors like infrastructure and health or education that more directly benefit the poor (Dennis, 2016).

The G20 2009 Pittsburgh Summit saw the explicit goal of a Fossil Fuel Subsidy Reform (FFSR) being formulated. The Sustainable Development Goal 12 also targets to “Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions” (12.c⁴) and more recently, the 2019 EU Green Deal aims for a broad tax reform to ensure a just transition in the energy sector⁵. This persisting misalignment between policies and the size of subsidies has been attributed to a failure to appreciate the political economy of subsidies that is made up of well-organized political groups (Victor, 2009). It also remains true that developing and implementing effective compensatory measures to mitigate the possible regressive impact on low-income households remains a challenge (Chepeliev & Mensrbugghe 2020). Still, much remains to be investigated to understand the full impact of a FFSR which is critical for moving the policy agenda forward as it helps policymakers craft legislation and communicate the case for the reform to the public (Coady et al., 2017).

The impact a reform would have on biofuel for example remains largely undefined. Biofuels are traditionally studied by modeling a subsidy calculated to achieve the demand targeted by a policy mandate (Kretschmer, et al. 2009; Laborde & Valin, 2012; Timilsina & Mevel, 2012) or by directly raising the share of biofuels in total final energy consumption (Delzeit, R. et al. 2018b). This type of simulation however fails to consider changes to FFS. This article sets out to investigate the link between fossil fuel consumption subsidies⁶ and biofuels. Using a Computable General Equilibrium (CGE) model we study a global fossil fuel subsidy reform and the EU’s biofuel mandate⁷.

We find that where both policies are implemented they can have a positive effect on one another. An FFSR can support the achievement of biofuel consumption targets at lesser costs when it is implemented

³https://ec.europa.eu/energy/sites/default/files/annex_to_the_state_of_the_energy_union_report_on_energy_subsidies_in_the_eu.pdf

⁴ <https://unstats.un.org/sdgs/metadata/?Text=&Goal=12&Target=12.c>

⁵ Available here: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN>

⁶ We follow the IEA and IMF definition and define fossil fuel consumption subsidies as subsidies to fossil fuels consumed by final users or consumed as input to electricity generation.

⁷ US quotas will be implemented at a later date.

in the same region. If the FFSR occurs abroad however this one can have a detrimental impact on the biofuel subsidies through a leakage effect. We simulate that the EU would need to spend USD 2 bn more on biofuel support to achieve the maximum allowed biofuel target of RED if the rest of the world phases-out subsidies but the EU does not. This represents a 1.9% increase in the total support for biofuels in the EU. Additionally, through their impact on the world market, biofuel subsidies can lead to leakages. As a result, a region that implements neither policy experiences an increase in its consumption of fossil fuels and decrease in its consumption of biofuels as a result of each policy being implemented abroad. In other words, while the policies can have a positive additive effect they also both lead to compounding leakages that are detrimental to the overall goal of reducing GHG emissions that they aim to achieve.

In summary, this study highlights the interconnectivity of the two policies through price mechanisms on the world market. To the best of our knowledge, policy measures on fossil fuels subsidies and biofuels have not been studied simultaneously. This is the knowledge gap the article aims to address. In particular, we analyze in subsequent scenarios the effects of: (1) a phase-out of fossil fuel subsidies; (2) a biofuel subsidy. We focus our analysis on the changes in prices, consumption, production, and trade of different fuels. The rest of the study is structured as follows: Section 2 introduces the DART-BIO model, the data used, and the definition of scenarios; Section 3 presents the results of the scenarios; Section 4 concludes. Finally, section 5 presents some of the limitations of the study and planned extensions.

2. Method

Fossil Fuel Subsidy Reforms (FFSRs) and biofuel policies provoke simultaneous adjustment in the market for fossil fuels and biofuels. At the same time, biofuels are embedded in a highly integrated agricultural market which relies on energy inputs to sustain production. Capturing these interactions is essential to understand the impact of each policy on one another. Partial equilibrium model that struggle to represent the link between sectors are badly suited to address question relating to international competitiveness effects (Ellis, 2010). Instead, Computable General Equilibrium (CGE) model have been recognized to be particularly well suited to capture these complex interactions (Delzeit et al., 2021; Kretschmer and Peterson, 2010). In fact, studies that consider indirect land use change from biofuels and the environmental impact of FFSR commonly use CGE models (Rosegrant & Msangi 2014, Chepeliev & Mensbrugghe 2020, Burniaux & Chateau 2014, S&S 2000, Ellis, 2010).

2.1 Model

We use a CGE model to examine the interconnectivity between fossil fuel and biofuel subsidy. More specifically, we use the DART-BIO model a version of the Dynamic Applied Regional Trade (DART) model designed to represent in details the agricultural sector, land use and conventional biofuels. The DART model is a global multi-sectoral, multi-regional recursive-dynamic CGE model that was developed in the 1990s by the Kiel Institute for the World Economy (Springer 1998). It has since then been widely applied to analyses international climate policies (e.g. Klepper and Peterson, 2006), environmental policies (e.g. Weitzel et al., 2012), energy policies (e.g. Klepper and Peterson, 2006b), and biofuel policies (e.g.

Kretschmer et al., 2009; Calzadilla et al., 2014; Zabel et al., 2019; Delzeit et al., 2018; Schuenemann and Delzeit, 2019).

The DART-BIO is the bio-economy and land-use version of the DART model. Fundamentally, they share the same structure but the bio-economy extension includes land heterogeneity and the complex production process chains of biofuels. The model is calibrated to a large extent on the GTAP9 database (Aguiar et al., 2016), which represents the global economy in 2011 and covers 57 sectors and 140 regions. The current DART-BIO model aggregation has 21 regions, 51 sectors and 21 factors of production.

Table 1: List of regions in DART-BIO

Central and South America		Europe	
BRA	Brazil	FSU	Rest of former Soviet Union
PAC	Paraguay, Argentina, Uruguay, Chile	CEU*	Central European Union with Belgium, France, Luxembourg, Netherlands
LAM	Rest of Latin America	DEU*	Germany
Middle East and Northern Africa		MED*	Mediterranean with Cyprus, Greece, Italy, Malta, Portugal, Spain
MEA	Middle East and Northern Africa	MEE*	Eastern European Union with Austria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia, Romania, Bulgaria, Croatia
AFR	Sub-Saharan Africa	NEW*	North-Western European Union with Denmark, Finland, Ireland, Sweden, United Kingdom
Asia		RNE	Rest of Northern Europe: Switzerland, Norway, Lichtenstein, Iceland
CHN	China, Hong Kong	North America	
IND	India	CAN	Canada
EAS	Eastern Asia. Japan, South Korea, Taiwan, Singapore	USA	United States of America
MAI	Malaysia, Indonesia	Oceania	
ROA	Rest of Asia	ANC	Australia, New Zealand, Rest of Oceania
RUS	Russia		

* Members of the European Union

To enable the modeling of the bio-economy several key sectors were disaggregated from the original GTAP database. The database also includes dedicated sectors for motor gasoline and motor diesel which are direct competitors of biofuels. Table 2 gives an overview of the sectoral aggregation in the model. In total 26, new sectors were added. The DART-BIO database thus includes 43 production activities and 51 commodities, since some activities produce more than one commodity (Table 2). Sectors were split using data from the meó Consulting Team⁸, F.O.Licht (F.O.Licht, 2015) and FOASTAT on production, price, and bilateral trade data. Production volumes were converted in USD before the trade share were used to distribute production assuming trade costs, tariffs, and export taxes/subsidies remained unchanged from original GTAP sector.

⁸ meó Consulting Team is a company providing consulting services with a special focus on renewables sustainability and climate change (www.meo-consulting.com).

Table 2: List of sectors in DART-BIO

Agricultural related products (29)		Energy products (14)	
<u>Crops</u>		COL	Coal
PDR	Paddy rice	CRU	Crude oil
WHT	Wheat	GAS	Gas
MZE	Maize	MGAS	Motor gasoline
GRON	Other cereal grains	MDIE	Motor diesel
PLM	Plam	OIL	Petroleum and coal products
RSD	Rapeseed	ELY	Electricity
SOY	Soy bean	ETHW	Bioethanol from wheat
OSDN	Other oil seeds	ETHM	Bioethanol from maize
C_B	Sugar cane and beet	ETHG	Bioethanol from other grains
AGR	Rest of crops	ETHS	Bioethanol from sugar cain
STR	Agricultural residues	ETHC	Cellulosic Bioethanol from agricultural residues
<u>Processed agricultural products</u>		<u>Biofuels</u>	
VOLN	Other vegetable oils	BETH	Bioethanol
SGR	Sugar	BDIE	Biodiesel from all other oilseeds
FOD	Rest of food	BDIE_PLM	Biodiesel from palm oil
PLMoil	Palm oil	UCOME	Biodiesel from used cooking oil
RSDoil	Rapeseed oil	<u>Non-energy products (3)</u>	
SOYoil	Soy bean oil	CRPN	Other chemical rubber plastic products
OSDNoil	Oil from other oil seeds	ETS	Paper, minerals and metals
SOYmeal	Soy bean meal	OTH	Other goods and services
OSDNmeal	Meal from other oil seeds	<u>Forest and forest products (2)</u>	
PLMmeal	Palm meal	FRS	Forestry
RSDmeal	Rapeseed meal	FRI	Forest related industry
DDGSw	DDGS from wheat		
DDGSm	DDGS from maize		
DDGSg	DDGS from other cereal grains		
UCO	Used cooking oil		
<u>Meat and dairy products</u>			
OLVS	Outdoor livestock and related animal products (cattle and other grazing animals, raw milk and wool)		
ILVS	Indoor livestock (swine, poultry and other animal products from indoor livestock)		
PCM	Processed animal products		

The DART-BIO model is a classical Walrasian general equilibrium model where the economy in each region is modelled as a competitive economy with flexible price and market clearing conditions. A single agent simultaneously represent utility maximizing consumer, profit maximizing producer, and the regional government. Production exhibit constant return to scale and is modeled using multi-level nested

constant elasticity of substitution (CES) production function. Final consumption is modelled with non-unitary income elasticities by using the linear expenditure system (LES) approach. The economies evolve over time through a sequence of single-period static equilibrium connected through capital accumulation and changes in labor supply for periods from 2011 until 2030. Changes in labor force, the rate of labor productivity growth, and the change in human capital accumulation determine changes in labor supply and productivity. Labor productivity and growth in human capital are both assumed to be constant but regionally differentiated. For a full technical description of the model see Delzeit et al (2021).

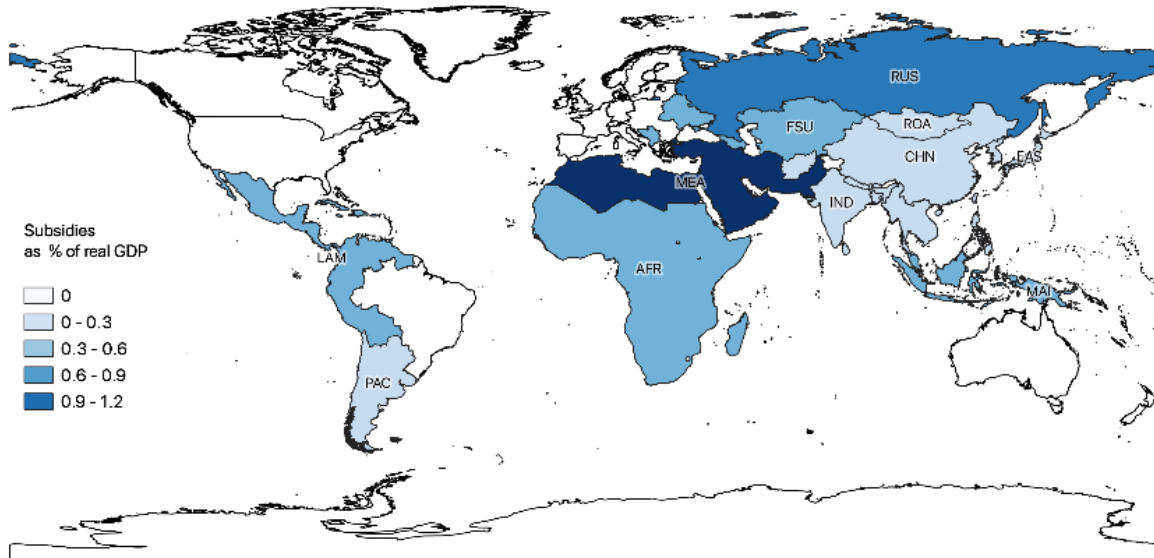
2.2 Data

The DART-BIO model is largely calibrated using the GTAP9 database (Aguiar et al., 2016). The current study complements this database using the GTAP9.2es extension that integrates ad-valorem pre-tax fossil fuel subsidies to the original database. This was accomplished by Chepeliev et al (2018) using IMF estimates on subsidies to fossil fuels that are consumed directly by end-users or consumed as inputs to electricity generation. Pre-tax subsidies from the IMF were derived using the price-gap approach that compares end-user prices to a reference price that corresponds to the full cost of supply. When the latter is larger, the IMF registers the difference as the pre-tax subsidy. It is important to note that, as this approach does not differentiate between import and domestic subsidies, they are assumed to be the same.

The IMF having updated its estimates in 2021 the author performed a simple check removing all subsidies no longer visible in 2021. Any rate higher in the GTAP9.2es database than in the 2021 IMF database was also replaced by the 2021 IMF rate. As a result, we simulate the fossil fuel consumption subsidies of four energy commodities included in the model, namely; diesel, gasoline, natural gas, and electricity. We note that this approach enables a swift data processing while ensuring conservative estimation. However, performing the method described by Chepeliev et al (2018) to integrate IMF fossil fuel subsidies to the GTAP data using the 2021 IMF rate would allow enhanced the accuracy of our simulations. This is planned for the next version of the article. Noticeably, the method entails replacing IMF consumption volume data with the one from GTAP when the IMF one is larger to avoid negative energy prices. The method also includes rescaling subsidies using GTAP-based import price as a supply cost when the subsidy rate is higher than GTAP-based international market price and energy imports over 50% of total consumption.

Figure 1 depicts the regional distribution of the total 2011 value of pre-tax consumption subsidies on all four commodities in percent of real GDP in the DART-BIO regions. The total value of subsidies as a percent of real GDP is largest in Middle East and North Africa (MEA) at roughly 1.2% followed by the Rest of the Former Soviet Union (FSU) at 0.9%.

Figure 1: Regional distribution of 2011 pre-tax fossil fuel consumption subsidies



2.3 Definition of scenarios

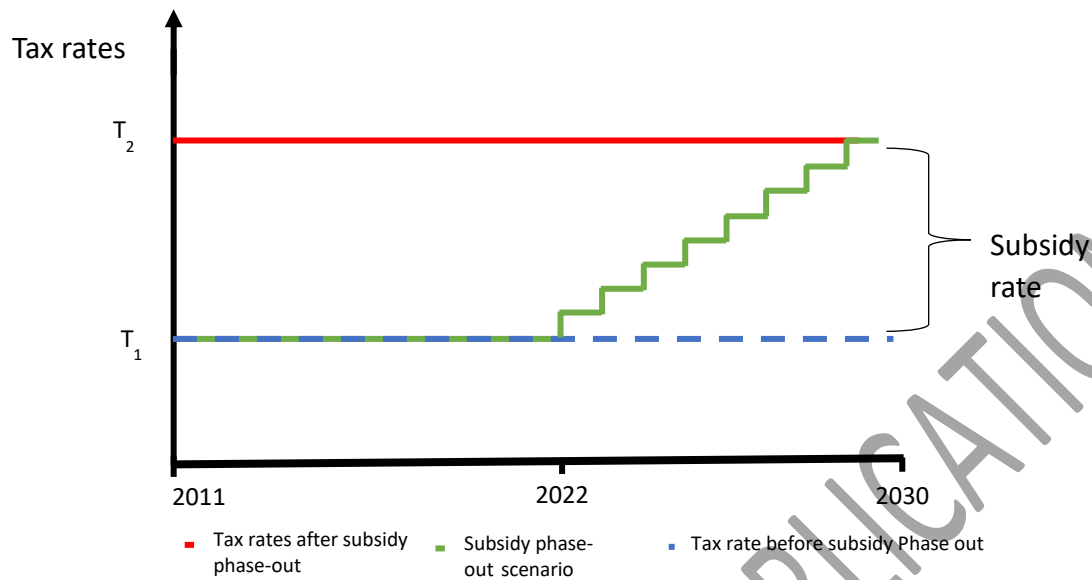
2.3.1. No fossil fuel subsidy phase-out and biofuel mandate Scenario (“Ref_sc”)

In the first scenario, the model original tax rates based on the GTAP9.2 database are updated to include the fossil fuel consumption subsidies derived during the data processing stage. This lowers the ad valorem taxes which are then kept constant through the model run. No policy is implemented to represent a *reference* scenario. As in the following scenarios, the reference scenario is calibrated to long term economic growth trends and key parameters. Labor productivity is calibrated to match the regional GDP growth projections of the OECD (2019). The capital stock is updated with the current period’s investments and depreciation, while labor supply changes according to regional workforce and population growth projections OECD (2019).

2.3.2. Fossil fuel subsidy reform with no biofuel mandate (“FFSR_NoBFQ_sc”).

In the second scenario, a Fossil Fuel Subsidy Reform (FFSR) is introduced by which all consumption fossil fuel subsidies integrated in the reference case are phase-out linearly from 2023 to 2030. The taxes that were updated to include the subsidies (T_1) increase every period after 2022 until they reach their initial GTAP9.2 database (T_2) level. The Fossil Fuel Subsidy Reform (FFSR) is there understood as the complete removal of fossil fuel consumption subsidies and is modeled by translating the phase-out of a subsidy as an increase in tax of the same magnitude.

Figure 2: Fossil fuel subsidy shock



2.3.3 Fossil Fuel Subsidy Reform with EU biofuel mandate ("FFSR_BFQ_sc")

In the "FFSR_BFQ_sc" scenario, fossil fuel subsidies are phased-out while a biofuel mandate is implemented in the EU. It combines the previous scenario "FFSR_NoBFQ_sc" with a biofuel mandate. The quota is designed so that the EU member states meet the 14% renewable energy in transport target with the maximum allowable share of biofuels according to the RED2. This means that the share of feed- and food-based biofuels are gradually increased to 7% (having the restriction on palm oil-based biodiesel in place) and the share of UCO based biodiesel to 1.7% until 2030.

2.3.4 No fossil fuel subsidy phase-out with EU biofuel mandate ("NoFFSR_BFQ_sc_sc")

In the last scenario, no phase-out of fossil fuel subsidies take place but the EU member states consume the maximum allowable share of biofuels according to the RED2 while banning palm-oil based biodiesel. In this scenario, the updated tax rates in the reference case would be kept constant while the consumption of biofuels is forced to increase to achieve the target defined in "FFSR_BFQ_sc".

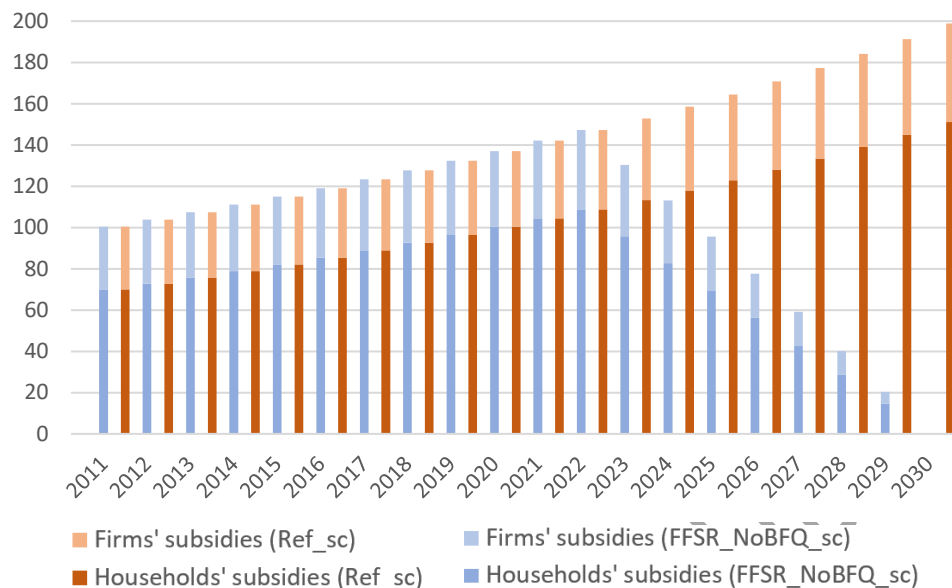
3 Results

Before discussing the results, we first present FFS based on the reference run. Considering our reference scenario with no policy shock we simulate global FFS to reach USD 137 billion in 2020 and slightly less than USD 200 billion in 2030. This is well below the USD 450 billion in 2020 estimated by Parry et al. (2021) and reflects the conservative approach taken during the data processing.

As per figure 3 below, starting at \$22 bn in 2023 the value of government spending on FFS avoided reaches the full amount of the subsidies by 2030. A relatively stable 70% of the total fossil fuel subsidy is made up of households' final consumption and 30% of intermediate consumption in both scenarios with

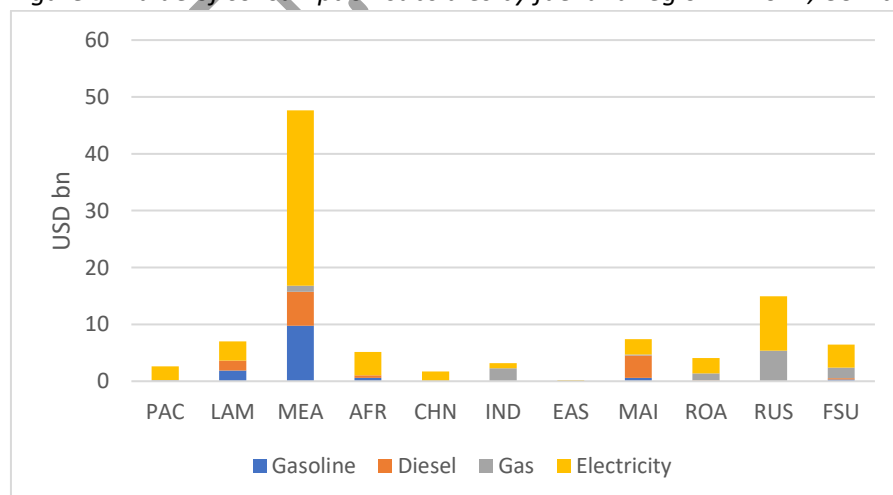
and without phase-out. Align with previous studies we find the total value of fossil-fuel subsidies to be the highest in the Middle East and North Africa (MEA), where they are simulated at USD 47 billion in 2011.

Figure 3: Global fossil fuel subsidies value in USD billion



Looking at the different fuels, we find that more than 50% of total subsidies come from the consumption of electricity (see Fig. 4). Coming second, gasoline subsidies are simulated at USD 13 bn in 2011. These are most prevalent in the Middle East and Northern Africa and Latin America where they reach USD 9 bn and USD 1.9 bn respectively. They are however also important in Sub-Saharan Africa where they are smaller in value but still make up more than 10% of the region's final consumption subsidies. Natural gas and diesel while prevalent in different regions but both add up globally to USD 12 bn in 2011. Natural gases are especially large in Russia and the rest of the former Soviet Union while diesel subsidies are largest in the Middle East and Northern Africa, Malaysia and Indonesia.

Figure 4: Value of consumption subsidies by fuel and region in 2011, USD bn

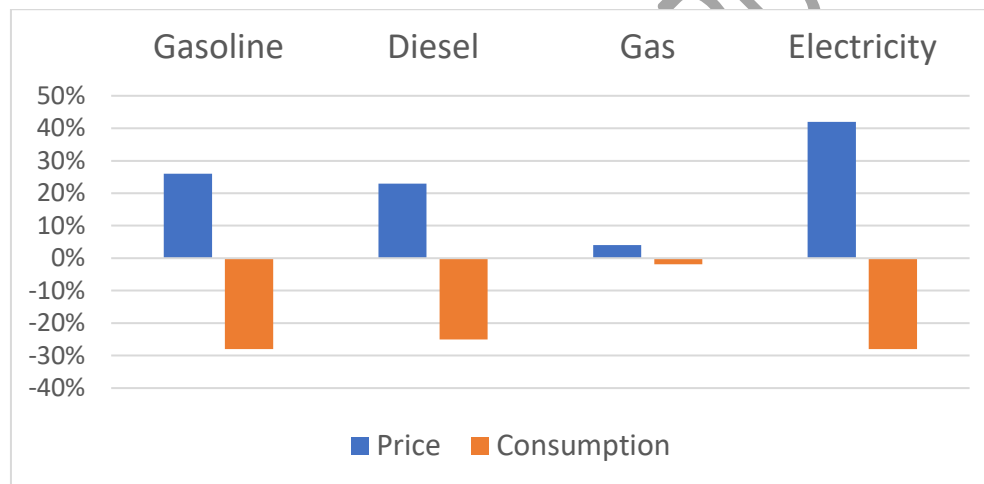


3.1 Impact on subsidized commodities

Our results on the subsidized fossil fuels energy markets widely match the one found in the literature that uses CGE models to study the impact of a fossil fuel consumption subsidies phase-out. Where the reform takes place, the price of the commodities no longer subsidized rises and consumption falls (see also Saunder & Schneider, 2000; Burniaux & Chateau, 2014; Ellis, 2010). Some of the production is diverted to the world market where prices fall. As a result, consumption increases in the rest of the world driven by an expansion of imports (ibid).

In the Middle East and North Africa (MEA), for example, the final consumption of domestic and imported motor gasoline, motor diesel, gas, and electricity are subsidized at a rate of 23%, 21%, 7%, and 31% respectively. As depicted in figure 5, the region experiences an increase in the price of these commodities related to the size of the subsidies phased-out which leads to a drop-in quantity consumed. When the percent change in price is larger than the one in quantity consumed, the value of consumption increases. In the present case, this is true of electricity and natural gas. This is consistent with a price elasticity below one.

Figure 5: 2030 Change in price and consumption quantity after the FFSR in MEA relative to reference case



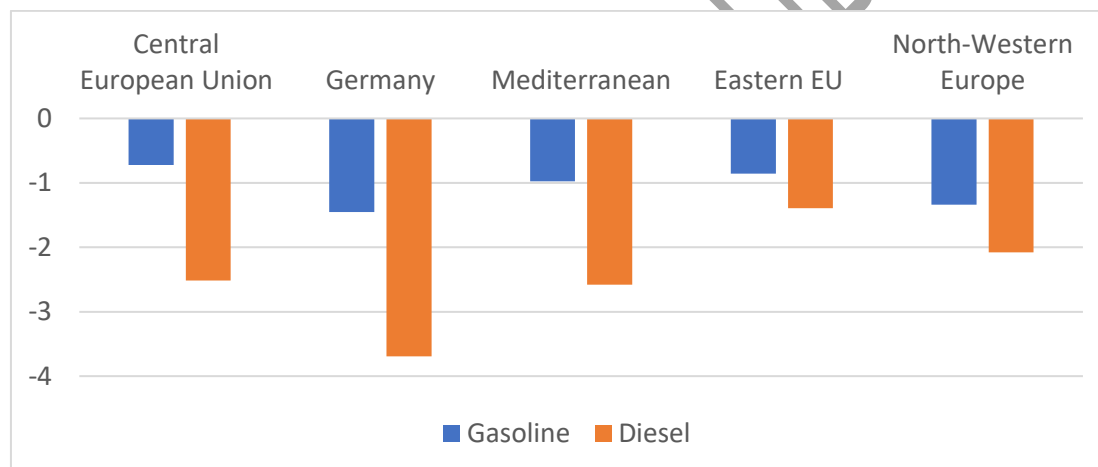
More broadly, we find that when removing the FFS, the quantity consumed of the previously subsidized energy goods in the regions implementing the FFSR drops by more than production. In combination with imports shrinking by more than exports, it reflects the diversion of some production to the world market. This puts downward pressure on world energy prices. The trade balance of the previously subsidies goods improves where the reform takes place while imports in the rest of the world increase as prices drop.

We note that some regions subsidized only a subset of the energy commodities that are subsidized in other regions. China and India for example only subsidize the consumption of electricity in our data. In these two regions, the consumption quantity of motor gasoline, diesel and natural gas increases as a result of the FFSR. At the same time, all other regions in Asia subsidize motor gasoline by 0.4% and experience an increase in its consumption volume. This suggests that a competitive effect can take place

in regions that reform FFS depending on the relative size of the subsidies. In regions without FFSR the trade effect leads to an increase in the consumption of energy commodities as their import price drops. In the EU for example, the consumption of motor gasoline and diesel increases by 0.3% and 0.5% respectively while the consumption of natural gas increases by 1.6% as a result of the reform taking place in the rest of the world. While mitigating some of the drop-in consumption where the subsidies were removed, overall, global quantity consumed contracts. In 2030, the value of global consumption across subsidized fossil fuel commodities falls by USD 65 bn in the phase-out scenario with no biofuel mandate (FFSR_NoBFQ_sc) relative to the baseline.

Comparing the changes in consumption when the FFS reform is implemented with and without an EU biofuel mandate, we find that the mandate does not have a large impact on the quantity of fossil fuel consumed outside of the EU. In other words, the shift in energy consumption in the EU as a result of the biofuel mandate does not lead to large impacts on fossil fuel markets in the rest of the world. This is not surprising considering that the biofuel mandate leads to a drop of USD 17 bn in the value of EU consumption of the motor gasoline and diesel in 2030. This represents a drop of about 6% for motor gasoline and 3% for motor diesel in overall EU region in 2030.

Figure 6: Change in the quantity of gasoline and diesel consumed in the EU when biofuel mandate is implemented, in 2030 (USD bn)



While marginal, we still do note that the EU biofuel mandate increases the consumption of motor gasoline and diesel in the regions outside of the EU by a total of USD 3.8bn. This occurs as the biofuel mandate, much like the fossil fuel subsidies reform, puts a downward pressure on the world market price for fossil fuels because demand drops in the EU. Ceteris paribus, regions outside of the biofuel mandate will increase their consumption of fossil fuel as imports of these becomes cheaper. Still, global fossil fuel consumption decreases as a result of the EU biofuel mandate in our simulation, suggesting that the effect where the quota is implemented dominates on the whole. We nevertheless note the possibility for countries to implement neither a biofuel mandate or fossil fuel subsidies phase-out. These regions would as a result experience the compound effect of both leakages on fossil fuel consumption as a result of the two policies. In Oceania for example, consumption of motor diesel increases by USD 0.15 bn from the FFSR and by USD 0.12 bn from the biofuel mandate.

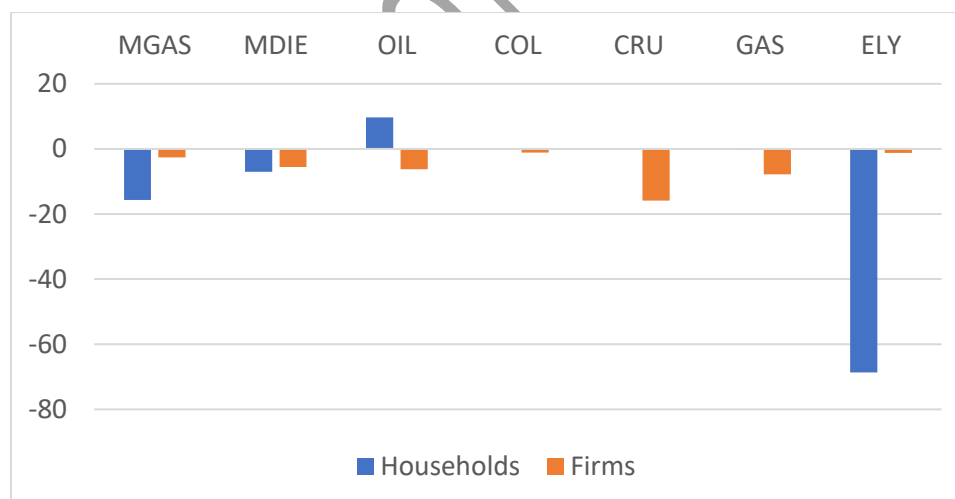
3.2 Impacts on non-subsidized fossil fuels

In regions where fossil fuel subsidies are phased-out, their consumption is partially substituted by alternative fuels. Energy commodities often enter the production of other energy goods which impact substitution possibilities. Subsidized energy goods can both be input in the production of non-subsidized energy goods as well as being produced using non-subsidized energy goods. Accordingly, the drop-in consumption of subsidized goods can imply downward pressure on the consumption of non-subsidized energy goods. Simultaneously, the price increase of subsidized goods can increase the cost of producing non-subsidized energy commodities.

Broadly speaking primary energies like coal, crude oil, and natural gas rely on primary factors of production (i.e. capital, labor, and natural resources) as well as chemical (CRPN) and minerals (FRI). These primary energy commodities then enter the production of secondary energies. Crude oil especially makes up the largest share of inputs in the motor gasoline, diesel, and oil sector. In turn, all energy commodities enter the electricity sector as inputs.

This explains the drop in intermediate consumption of the non-subsidized fossil fuel in regions like Middle East and North Africa (MEA). As depicted in figure 7, the intermediate consumption of crude oil drops by USD 16 bn in 2030 in MEA as a result of the FFSR. This is a comparatively larger change than for coal and gas and can be explained by the fact that crude oil makes up more than 60% of motor gasoline and diesel's total input share in the region. At the same time, the drop-in consumption and price of crude oil increases the final consumption of the "oil" sector as it is a major input in its production. We note the drop in the intermediate consumption of oil is consistent with it being the second-largest input in the electricity sector in MEA. Overall, the total quantity of consumed oil by 2030 increases by 1.4% as a result of the FFSR.

Table 7: changes in quantity of fossil fuels consumed in MEA in 2030, USD bn



These mechanisms are consistent across the regions phasing out subsidies and we note that when motor gasoline and diesel are not subsidized their consumption tend to increase as a result of the reform. Regions that did not phase-out subsidies increased their consumption across energy commodities, but

globally, the direction of the changes in total consumption matches the patterns observed on the figure 7 above.

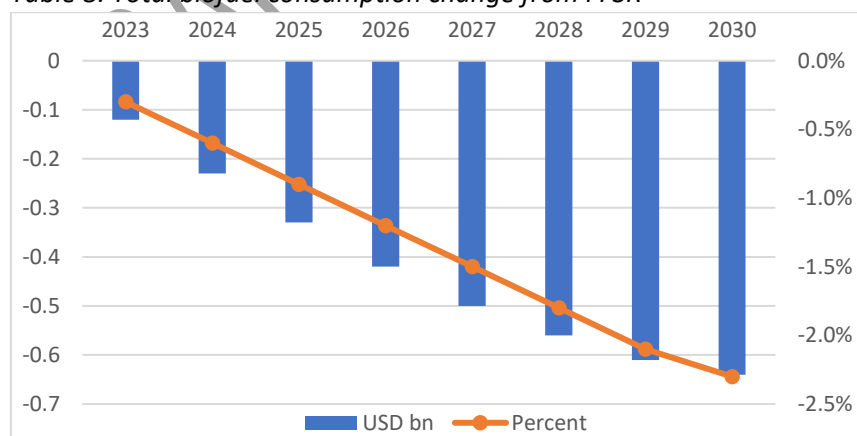
As expected, like for subsidized goods, the EU biofuel mandate has little impact on non-subsidized commodities outside of where it is implemented. We do nevertheless find that their consumption tends to increase as a result of the impact of the quota on international markets. In the EU where the biofuel mandate has a more direct effect, we find that it tends to lower consumption of non-subsidized fossil fuels but again this is marginal. In the region, crude oil is the most affected non-subsidized commodity because of its role in the production of subsidized goods competing with biofuels directly in the transport sector. We simulate that the value of its consumption drops by 1.6% in the EU by 2030.

3.3 Impact on biofuels

Comparing the FFSR_NoBFQ_sc and reference scenarios, we find that in the region implementing the FFSR the substitution away from subsidized fossil fuels also occurs in favor of biofuels. Bioethanol consumption in MEA for example increases by USD 0.018bn as a result of the FFSR. While this is small in absolute term it does represents a 600% change relative to the reference baseline consumption. More broadly, regions phasing out subsidies on motor gasoline and diesel in the FFSR only scenario compared to the baseline generally see their consumption of bioethanol increase as a result of an expansion of imports from major bioethanol producers, namely, the US, Brazil and the Central European Union.

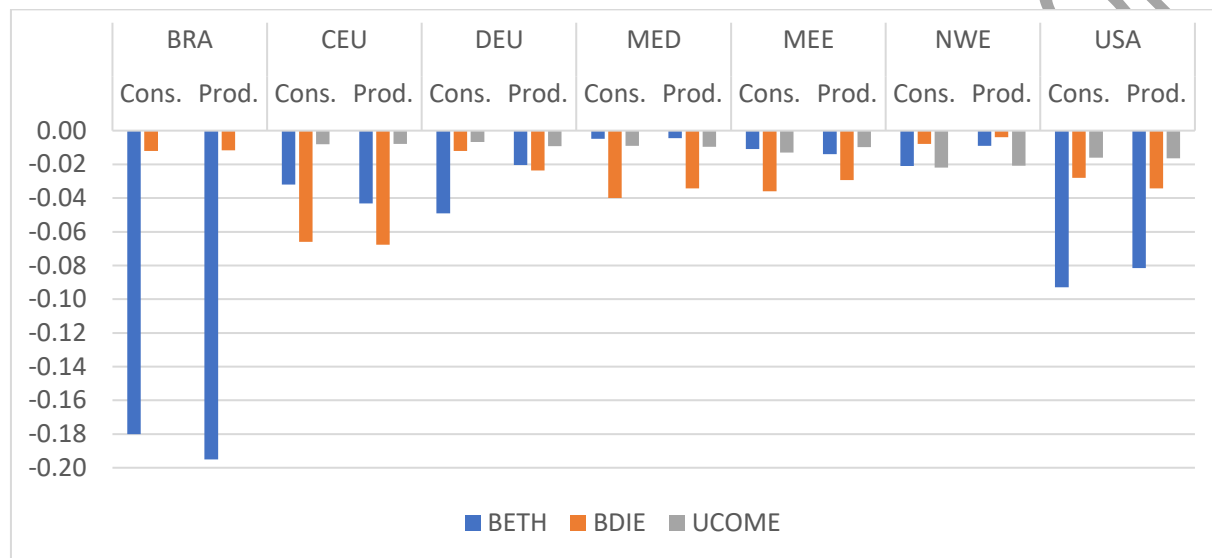
This increase in the import of biofuels in the subsidy reform's regions occurs as the consumption in the rest of the world drops. This is the result of biofuels becoming relatively cheaper compared to fossil fuels where subsidies were removed while becoming relatively more expensive outside of the subsidy reform area. This implies the diversion of biofuels consumption from major producers who did not phase-out FFS to exports in regions that did implement the FFSR. As an example, bilateral trade of Bioethanol from the Central European Union to Middle East North Africa increased by USD 0.018 bn in 2030 when the FFSR is implemented relative to the reference scenario. Globally we however find that this is not enough to overcome the drop-in consumption that takes place in the regions that did not implement the FFSR. In 2030, biofuels consumption is simulated to decrease by USD 0.64 bn or 2.3% globally as a result of a fossil fuel consumption reform.

Table 8: Total biofuel consumption change from FFSR



We find that the largest single country drops in consumption as a result of the FFSR is observed in the bioethanol sector in Brazil and the USA, the main producers of this commodity. Each EU region experiencing the largest drop for both bioethanol and biodiesel sector after the US and Brazil. These changes being driven by drop in production in the US and Brazil while in the EU intra-regional trade also plays a role in the observed drop. We note that not all country experiences an increase in the trade balance for these fuels. As in the case of Brazil for example production drops by more than consumption suggesting that the drop-in exports are larger than the one in imports.

Figure 9: Change in quantity consumed and produced of each biofuel following the FFSR relative to baseline in 2030, USD bn



Our simulations suggest that a FFSR would lower the share of conventional biofuels in total transport fuel consumption in the US by 0.1% and in the EU regions by 0.04% to 0.09% if not biofuel policies are in place. Considering biofuel mandates' targets defined in volumes or as a percentage of consumption, if these are implemented in regions where there are no FFS, our result suggests that a global FFSR would be detrimental to their achievement.

Aligned with these results, when the simulations include the achievement of the EU' biofuel mandate through a subsidy, we find that the government support must increase to achieve a set consumption share target when the FFS reform is implemented. As a whole, the EU's subsidy on biofuel increases by USD 2.22 bn to achieve its target as defined in "FFSR_BFQ_sc" over the period of the fossil fuel subsidy reform period (2023-2030). As a percentage of the total subsidy paid in the absence of a phase-out this represents a 1.9% increase in total subsidy. Looking at the breakdown by biofuel category, we find that biodiesel makes up 70% of the total subsidy increase.

Table 3: Change in the total value of the biofuel subsidy in bn USD to reach quota when comparing the FFSR_BFQ_sc and NoFFSR_BFQ_sc_sc scenarios

	Central EU	Germany	Mediterranean	Eastern EU	North-Western Europe	Total
Bioethanol	0.08	0.18	0.03	0.07	0.19	0.56
Biodiesel	0.33	0.43	0.32	0.13	0.20	1.42

Biodiesel from used cooking oil	0.06	0.06	0.07	0.02	0.04	0.24
Total	0.47	0.67	0.42	0.23	0.43	2.22

3.4 Impact on other sectors and economies as a whole

We find that the FFSR increases world GDP by about 0.1% or USD 126 bn in 2030. This economy-wide effect appears to be mostly driven by the changes in the value of consumption. Total consumption in volume tends to drop in regions where the subsidies were phased-out as a result of the decrease in fossil fuel consumption. Price for the previously subsidized goods in these regions however increases and as a result, the drop-in value is smaller than the one in volume. Freed up resources from the FFSR are allocated to other sectors of the economy and we find that demand for most other commodities tends to increase while their price rises. These two effects combined tend to lead to an increase in the overall value of consumption in the regions phasing-out fossil fuels. Outside of the reform area, we also find overall consumption tends to increase. The value of energy consumption may drop from the decrease in price but the value of consumption in the other sectors tends to increase.

Table 4: Global changes in consumption value by product categories⁹ comparing the FFSR_NoBFQ_sc scenario to reference case (Ref_sc), USD bn

Crops	Processed agri. Prd.	Meat and dairy	Energy excl. biofuels	Biofuels	Forest and forestry	Services	Other	Total
36.2	21	16.9	(-142)	(-0.7)	6	75	40	52

We note that this is not the case for biofuels, their feedstock, and by-products. As noted earlier, when a FFSR is implemented the global consumption for biofuels drops because of the change in the consumption of major biofuel producing regions which happen to be outside of the FFSR area. Accordingly, the demand for the inputs used in their production (i.e. vegetable oils) tends to decrease together with the consumption of their by-products (i.e meals and DDSG) in these regions. Brazil that produces bioethanol from sugar for example sees its consumption and production of sugar beet decrease while it is the case for maize in the US. More broadly, we find the service and other good sector to benefit most from the reform. This is easily explained by the fact that the two sectors have the largest share of total consumption in all regions.

Considering the total consumption change across regions and products we find the FFSR to lead to a worldwide increase of USD 52 bn in 2030. This drives the global GDP increase observed in the simulation but it is important to recognize that not all regions benefit from the FFSR. Four regions, namely; Russia, Rest of Northern Europe, Canada and Oceania are found to experience a drop in GDP. Unlike most of the rest of the world, the total consumption in value in these regions decreases and comparing the breakdown by sectors this appears to be in part driven by a drop in the consumption value of the service

⁹ As per table 2

sector. One explanation for this change is that these regions are relatively large net exporters of fossil fuel commodities. As the literature previously found it would be possible for the terms-of-trade losses in these regions to more than offset the efficiency gains from improved resource allocation domestically. This is however contrasted by our result that the term of trade of these regions barely changes.

Comparing the impact of the fossil fuel phase-out with and without an EU biofuel mandate, we find the EU mandate has a very limited impact on the overall economies outside of the EU, especially even when considering large scale factors like real GDP. Still, we do note that real GDP increases slightly more in the EU when no quota on biofuels is put in place and since this has virtually no impact outside the EU, the effect is carried over to global real GDP. As a result, the increase in world GDP from the FFSR reform is slightly lower than the EU quota when both policies are implemented. Two notable exceptions are the USA and Brazil which benefit slightly from the EU quota as foreign demand for the biofuel they produce increases.

4 Conclusion

In summary, we find that a FFSR and biofuel mandate have symmetric effects on the consumption of fossil fuels and biofuels where they take place. Phasing out fossil fuel subsidies lowers their consumption as their prices increase. This makes biofuels relatively more attractive thereby increasing their consumption. This is particularly evident in the case where the subsidies removed were applied to motor gasoline and diesel which are direct substitutes for biofuels. A biofuel mandate increases the consumption of biofuels while lowering the consumption of fossil fuels. As a result, these policies can have a positive additive effect. *Ceteris paribus*, a region that simultaneously implements a motor gasoline and diesel subsidy phase-out as well as a biofuel mandate would need to spend less on biofuel subsidies to reach a set target of consumption (in volume or share) than if it did not implement a FFSR.

These impacts are however diametrically opposed outside of the regions where the policies are implemented. As a result, while the policies have the potential to be complementary they can also be conflicting with one another. As some of the fossil fuel consumption is diverted to the world market where subsidies are phased-out, consumption in regions that did not phase-out subsidies increases as import price drops. This is a form of leakage well documented in the literature (Saunders & Schneider, 2000; Burniaux & Chateau, 2014; Ellis, 2010). A region trying to achieve a biofuel mandate target in volume or consumption share would therefore suffer from the rest of the world implementing a FFSR as its consumption of biofuels would be driven down while its consumption of fossil fuels would be driven up by the reform. This is the case for the EU in our simulations. If we compare the case where the EU does not phase-out fossil fuel consumption subsidies while the rest of the world does to the case where no country phases-out fossil fuel subsidies. We simulate that the EU would need to increase subsidies to biofuels by USD 2 bn over the 2023-2030 period to achieve the share of consumption of biofuels in total transport fuels defined in the current RED policy.

In addition, to the leakage of fossil fuel consumption from the FFSR, there exists another form of leakage from the biofuel mandate. Like for the FFSR, the biofuel mandate lowers the demand for fossil fuels which increases consumption in regions outside of the quota as import prices drop. As a result, the consumption of fossil fuels in a region can increase from the implementation of both policies in another region. In Oceania for example, consumption of motor diesel increases by USD 0.15 bn from the FFSR

and by USD 0.12 bn from the biofuel mandate. At the same time consumption of biodiesel drops by \$ 0.14 bn from the EU mandate and by \$0.01 bn from the FFSR.

These mechanisms highlight the two-way interconnection of both policies. A fossil fuel subsidy reform and biofuel mandate can both shift some consumption away from fossil fuel to biofuels and also shift consumption away from biofuels to fossil fuels. The transition to renewable energies driven by the FFSR in the regions where it is implemented is small in our simulation. This likely is the result of the FFS being most pervasive in our data where the consumption of biofuels tends to be initial small, suggesting that these fuels are not competitive in these regions. In fact, our simulation suggest that a fossil fuel subsidy reform has the potential to lower global biofuel consumption if only the removal of pre-tax subsidies is considered. The drop-in energy consumption is instead found to be compensated in larger part by other non-subsidized fossil fuels where the reform takes place. This partial substitution is driven by the complex pattern of input-share between energy commodities. Inputs and by-products of biofuels are also found to increase/decrease when biofuel consumption increase/decrease. The direction of this change, like for fossil fuels, being determined by the policy mix of the region considered.

Our result, therefore, suggests that studies on biofuel mandates should consider fossil fuel subsidies and their phase-out. Similarly, accounting for the impact of biofuel policies when studying FFSR can prove to be a meaningful avenue to improve results' accuracy. Studies that do not take the interlinkage of these two policies have the potential to both underestimate or overestimate the support a government would need to give to biofuels to achieve a set consumption target and/or the level of change in fossil fuels consumption from a FFSR. Both impacts are relevant to climate mitigation studies. The result that FFS are most pervasive in regions that do not have biofuel mandates suggest that these studies are more likely to overestimate the government support need to reach biofuel targets. This can however be put into question as only part of the global subsidies estimated by the IMF are included in the article.

5 Limitations

This paper highlights the importance of understanding the impact of a fossil fuel subsidy reform and the synergies it would have with current biofuels policies. Nonetheless, the approach raises some issues and is not without limitations:

Countries with the highest FFS may also not be the ones most likely to implement a reform. Accordingly, relatively small subsidies omitted in this study may be more likely to be phased-out and coincidentally these may very well be located in regions with biofuel mandates. The US and the EU for example do not subsidize fossil fuels in our study which is factually incorrect. This is especially relevant in light of our finding that if the rest of the world phase-out fossil fuel subsidies but not the EU, it would need to spend an additional USD 2 bn to support the achievement of the RED target. We however know that the EU is estimated to have spent €52 billion on fossil fuel subsidies in 2020¹⁰. In other words, the increased spending on biofuels amounts to 4.2% of the spending on FFS. Furthermore, we know that removing FFS would in fact benefit biofuels. Considering that the EU implement a FFSR, the USD 2 bn estimation would

¹⁰ [annex to the state of the energy union report on energy subsidies in the eu.pdf \(europa.eu\)](#)

shrink. It is even possible for this figure to go down to zero depending on the impact of the size of the effect of the FFSR.

To answer these questions, a less conservative data processing will be undertaken to reach an estimate of total global subsidies closer to that of the IMF. At the same time, considering post-tax subsidies to reach some level of efficient pricing is a promising avenue of research and likely to yield complementary results to our study. This is especially pertinent as regions where biofuel mandates are established often do so with climate mitigation goals in mind which is a key rationale to reach fossil fuel-efficient prices.

Regardless we note that pre-tax subsidies only include consumption subsidies that turn the retail price below supply cost. Ideally, we would explicitly model and quantify the impact of all forms of fossil fuel subsidies (not only the one observed by the price-gap approach, as well as on production, production factors, etc) but such an approach is not feasible due to the lack of data.

The DART-BIO model aggregates domestic and import tax rates. Fortunately, there is some consistency between these two in the database. When there is a difference, however, this implies that the phase-out has a competitive effect based within an economy through factor reallocation and through the trade balance of goods abroad.

In a similar fashion, the regional aggregation of the model may lead to bias. Approaches to reduce the need to pre-model aggregation have been documented (Britz & Mensbrugghe, 2016) and would be a meaningful avenue to improve the accuracy of the results.

It should also be noted that subsidy rates were not stable during the 2011 to 2022 period. While the data processing approach was conservative in nature, the evolution of the rates during this period could have led to changes in the economy relevant to our investigation.

As noted, our data on the subsidies is also very conservative in nature, the underestimation in certain regions and goods implies also implies a potential bias in our results.

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APPENDIX

Difference in the share of biofuels in EU regions between scenario 3 and 4 as a result of the calibration process.

Table 7: Difference in biofuel shares from the calibration process between scenario 3 and 4

	CEU	DEU	MED	MEE	NWE
BETH	(-0.001%)	(-0.003%)	0.005%	(-0.010%)	0.016%
BDIE	0.006%	0.000%	(-0.002%)	(-0.002%)	(-0.001%)
BDIE_PLM	0.000%	0.000%	0.000%	0.000%	0.000%
UCOME	(-0.004%)	(-0.004%)	(-0.002%)	(-0.008%)	(-0.004%)