The interconnections between Fossil Fuel Subsidy Reforms and biofuels mandates

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Abstract

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'. At the same time, mandates like the Renewable Energy Directive (RED) that aim to increase biofuel consumption and often inscribed in government energy transition strategy. These two fuel types are known to interact through price mechanisms (Delzeit et al. 2021c; Winchester & Ledvina, 2017), yet the impact of fossil fuels and biofuel 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 phasing out subsidies increases the price of fossil fuels and lowers consumption. Regions with biofuel mandates would therefore benefit from a Fossil Fuel Subsidy Reform (FFSR) as the government support needed to reach a biofuel consumption target would lower. Some fossil fuel consumption would however be diverted to exports, resulting in downward pressures on the world price. Regions with no or relatively low subsidies, would therefore experience an increase in fossil fuel consumption and require larger government support to reach their biofuel targets. Still, regardless of the leakage effect of both policies, the policies have an additive effect and both lead to a drop in the consumption of fossil fuels and an increase in the consumption of biofuels while lowering government spending.

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 (Calzadilla, A. et al. 2016). Notable examples include the European Union's Renewable Energy Directive (RED) implemented in 2009 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 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),

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and $450 billion in 2020 (Parry et al, 2021). In the EU alone, the European Commission estimated that in the EU they equal €52 billion[3] 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 (Victor, 20009). 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). More generally, they are distortive, generate inefficiencies in the energy markets (OECD/IEA, 2021), and create a burden on public accounts (Hayer, 2017).

With these in mind, the notion of a phase-out is not new. In 2009, The G20 Pittsburgh Summit explicitly formulated the goal of a Fossil Fuel Subsidy Reform (FFSR). In the global context still, Sustainable Development Goal 12 targets to "rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption" (12.c4), and more recently the Glasgow Climate Pact called for "accelerating efforts toward the phase-out of […] inefficient fossil fuel subsidies"[5]. At the supranational scale, we also find examples of targets like the 2019 EU Green Deal that aims for a broad tax reform to ensure a just transition in the energy sector[6], while at the national level, several countries explicitly refer to a phase-out in their Nationally Determined Contribution (Global Subsidies Initiative, 2019).

This persisting misalignment between targeted policies and the size of subsidies has been attributed to a failure to appreciate the political economy of subsidies (Victor, 2009). The lack of confidence in the governments and weak institutions were also highlighted as barriers to action (Hayer, 2017). Developing and implementing effective compensatory measures to mitigate the possible regressive impact on low-income households also remains a challenge (Chepeliev & Mensrbugghe 2020). Still, addressing the concerns over the general impact of a reform is critical for moving the policy agenda forward. A more complete understanding of the topic would support policymakers craft legislation and communicate the case for the reform to the public (Coady et al., 2017). As highlighted by Saunders and Schneider (2000, p3) a reform "likely to have significant general equilibrium effects […] importance in this context are the interaction between the markets for coal, gas, oil products and other sectors of the economy".

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 (Kretschemer, 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

[3] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0950
[4] https://unstats.un.org/sdgs/metadata/?Text=&Goal=12&Target=12.c
[5] Glasgow Climate Pact FCCC/PA/CMA/2021/L.16 (UNFCCC, 2021).
[6] Available here: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN

consumption subsidies[7] and biofuels. Using a Computable General Equilibrium (CGE) model we study a global fossil fuel subsidy reform and the EU's biofuel mandate[8].

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 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) models 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

[7] 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.
[8] US quotas will be implemented at a later date.

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 analyze 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 splited using data from the meó Consulting Team[9], 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.

Table 2: List of sectors in DART-BIO

Agricultural related products (29)	
Crops	
PDR	Paddy rice
WHT	Wheat
MZE	Maize
GRON	Other cereal grains
PLM	Plam
RSD	Rapeseed
SOY	Soy bean
OSDN	Other oil seeds
C_B	Sugar cane and beet
AGR	Rest of crops
STR	Agricultural residues
Processed agricultural products	
VOLN	Other vegetable oils
SGR	Sugar
FOD	Rest of food
PLMoil	Palm oil
RSDoil	Rapeseed oil
SOYoil	Soy bean oil
OSDNoil	Oil from other oil seeds
SOYmeal	Soy bean meal
OSDNmeal	Meal from other oil seeds
PLMmeal	Palm meal
RSDmeal	Rapeseed meal
DDGSw	DDGS from wheat
DDGSm	DDGS from maize
DDGSg	DDGS from other cereal grains
UCO	Used cooking oil
Meat and dairy products	
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

Energy products (14)	
COL	Coal
CRU	Crude oil
GAS	Gas
MGAS	Motor gasoline
MDIE	Motor diesel
OIL	Petroleum and coal products
ELY	Electricity
ETHW	Bioethanol from wheat
ETHM	Bioethanol from maize
ETHG	Bioethanol from other grains
ETHS	Bioethanol from sugar cain
ETHC	Cellulosic Bioethanol from agricultural residues
Biofuels	
BETH	Bioethanol
BDIE	Biodiesel from all other oilseeds
BDIE_PLM	Biodiesel from palm oil
UCOME	Biodiesel from used cooking oil

Non-energy products (3)	
CRPN	Other chemical rubber plastic products
ETS	Paper, minerals and metals
OTH	Other goods and services

Forest and forest products (2)	
FRS	Forestry
FRI	Forest related industry

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

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 a 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 Subsidies and calibration

The DART-BIO model is largely relies on the GTAP9 database (Aguiar et al., 2016). The current study complements this database using the IMF's publicly available data on fossil fuel subsidies published in 2019 and 2021 covering the period 2003-2019 and 2015-2025 respectively.

The IMF derives pre-tax subsidies using the price-gap approach by comparing average end-user prices with free-market reference prices reflecting the full cost of supply. Support measures that do not influence end-user prices are therefore not captured. The method however benefits from being relatively low data-intensive and measuring a well-accepted category of subsidies (UNEP, 2019). Estimates are made for 188 countries as well as for both gasoline and diesel separately allowing the integration of the subsidies with no additional disaggregation. Post-tax subsidies are also included, which are defined as the exemption from the corrective Pigouvian tax reflecting the cost of externalities. These include the cost of local air pollution mortality, broader costs associated with the use of fuels in road vehicles, and global warming (Coady et al, 2019). While further from the WTO 1994 definition of a subsidy ratified in the Agreement on Subsidies and Countervailing Measures (ASCM), post-tax subsidies offer an interesting opportunity to investigate efficient pricing policies considering the duality of the topic that explore biofuels in relation to fossil fuels.

Ad valorem subsidies are applied to the Armington aggregate of imports and domestic consumption as negative sales taxes. Consumers and firms face the same rates, as well as industries consuming the same intermediate. The model base year is recalculated following the integration of the subsidies to minimize the deviation from the initial SAM values which implicitly reflected the distortions of the market. The model is calibrated using labor productivity to replicate trends in the production of motor gasoline and diesel between 2011 and 2020 using IEA data from the 2022 World Energy Outlook[10]. These included the share of each region in total production as well as global cumulative growth over the entire period. Following the same procedure, crude oil production is calibrated for the rest of the simulation run using

[10] https://www.iea.org/reports/world-energy-outlook-2022

projections by the Joint Research Center 2021 GECO baseline scenario[11] as the IEA no longer offers policy-free baselines. Simultaneously, labor productivity is calibrated to match the regional GDP growth projections of the OECD (2019). We note that, 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).

2.3.1. *Reference scenario ("Ref")*

In the first scenario, yearly fossil fuel subsidies between 2011 and 2022 from the IMF database are integrated into the model. Assuming no policy change, after 2022 the rates are kept constant. The reference scenario is also calibrated to mirror the biofuel consumption of different vegetable oils in biodiesel and grain in bioethanol assuming the regions gradually and linearly achieve their current mandates targets by 2030.

Unlike for the rest of the world, the EU mandate is implemented as maximum allowable consumption shares that constrain each region's biofuel consumption instead of a minimum blending rate or consumption target. Considering that 14% share of renewables in total transport fuel consumption until 2030 cannot be met without a sufficiently large amount of biofuels, we assume that 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. Finally, since the RED2 stipulates that the share of biodiesel from palm oil is classified as "high-iluc risk" its share in road transport is gradually reduced to 0 from 2023 until 2030.

2.3.2. *Global Fossil fuel subsidy reform ("Global_FFSR ")*

In the second scenario, a global Fossil Fuel Subsidy Reform (FFSR) is simulated. Starting in 2023 the subsidies showed in table 1 below are linearly phased out until 2030.

Table 1:

	Motor Gasoline	Motor Diesel
OPEC	26.0%	61.6%
PPEC (Partners of OPEC)[12]	1.3%	8.6%
Former Soviet Union		0.3%
Russia		1.5%
Oceania		0.03%
Rest of Middle East and Africa	1.9%	7.7%

[11] Joint Research Centre Data Catalogue - Baseline GECO 2021 - European Commission (europa.eu)

[12] Countries who signed the 2016 Declaration of Cooperation (DoC) with OPEC. These include; Azerbaijan, Kingdom of Bahrain, Brunei Darussalam, Kazakhstan, Malaysia, Mexico, Sultanate of Oman, the Russian Federation, Republic of Sudan, Republic of South Sudan. An exception is made for the Russian Federation that is depicted as a single region and Malaysia which is aggregated with Indonesia due to their geographical closeness as well as the similar and important role they play in worldwide biofuel production and consumption.

Rest of Asia	0.02%	0.2%
Malaysia and Indonesia	3.6%	18.1%
Latin America	0.6%	1.5%

Net importing regions like the EU and USA show no subsidies on transport fossil fuels in our data. This does not mean either region does not subsidies fossil fuel but could reflect a difference in subsidy type, directly or not influencing end-user price

2.3.3 *Partial Fossil fuel subsidy reform ("Global_FFSR ")*

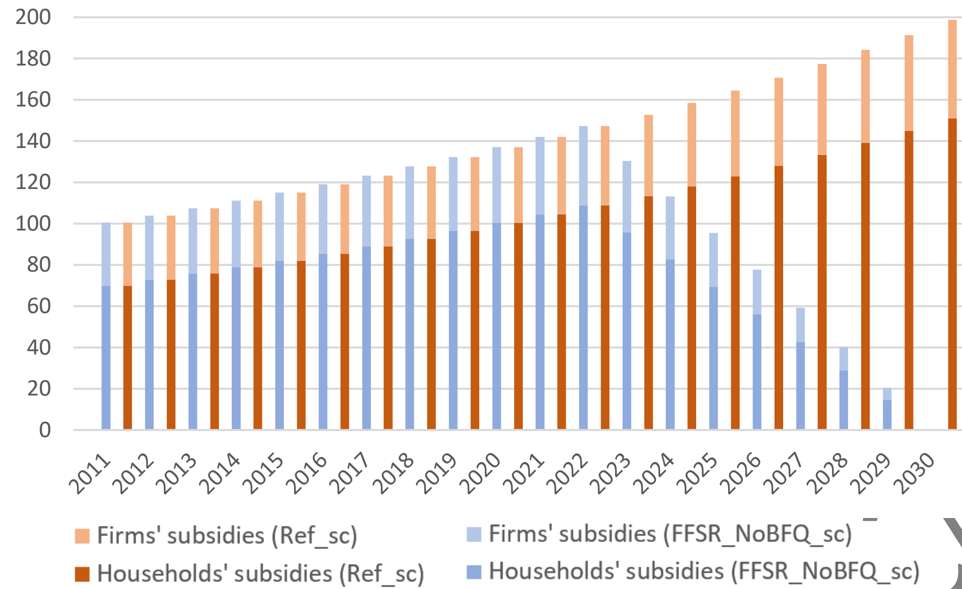
In the third scenario, a Fossil Fuel Subsidy Reform (FFSR) is introduced by which fossil fuel subsidies integrated in the reference case are phase-out linearly from 2023 to 2030 in the regions with biofuel mandates (Bolded regions in table 1).

3 Results

As noted by previous researchers using the IMF database, fossil fuel subsidies are concentrated in net exporting countries like in the OPEC region (Chepeliev & Mensbrugghe, 2020**).** This remains true considering the net export of crude oil together with gasoline and diesel subsidies which in 2022 made up about 23% of subsidies in the IMF database. The OPEC region being a prime example, being both the largest net exporter of crude oil and having the highest subsidy rate for both fuels among all regions.

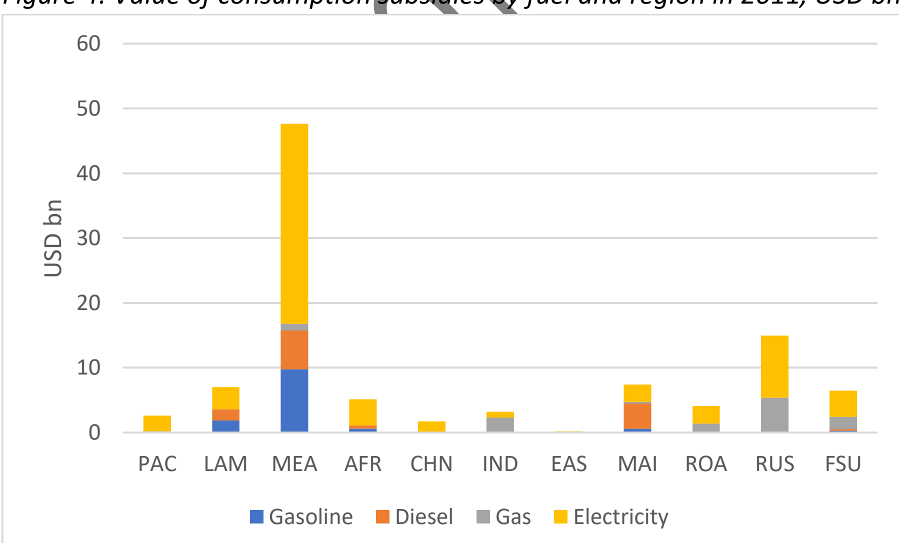
As per figure 3 below, starting at $22 bn in 2023 the value of government spending on FFS avoided reaches the full amount of the subsidies by 2030. A relatively stable 70% of the total fossil fuel subsidy is made up of households' final consumption and 30% of intermediate consumption in both scenarios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

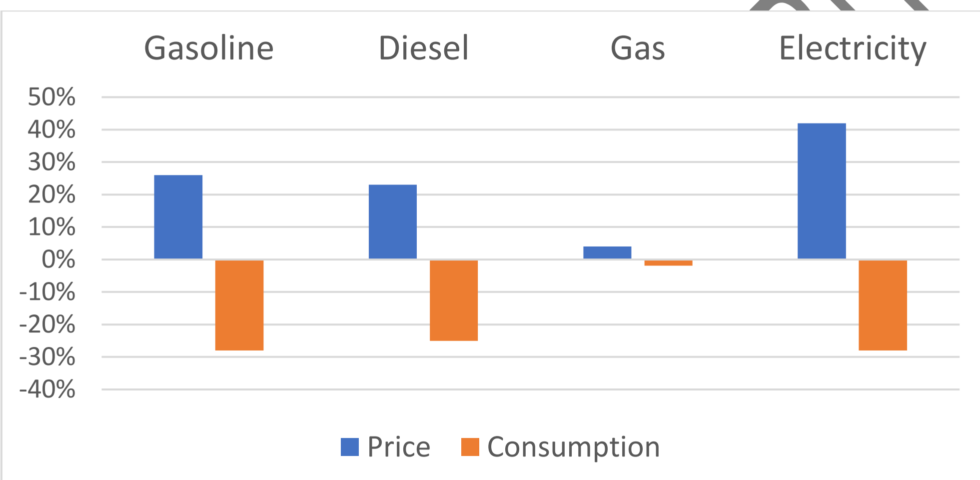


3.1 Impact on subsidized commodities

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; Taghvaee et al., 2022). 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



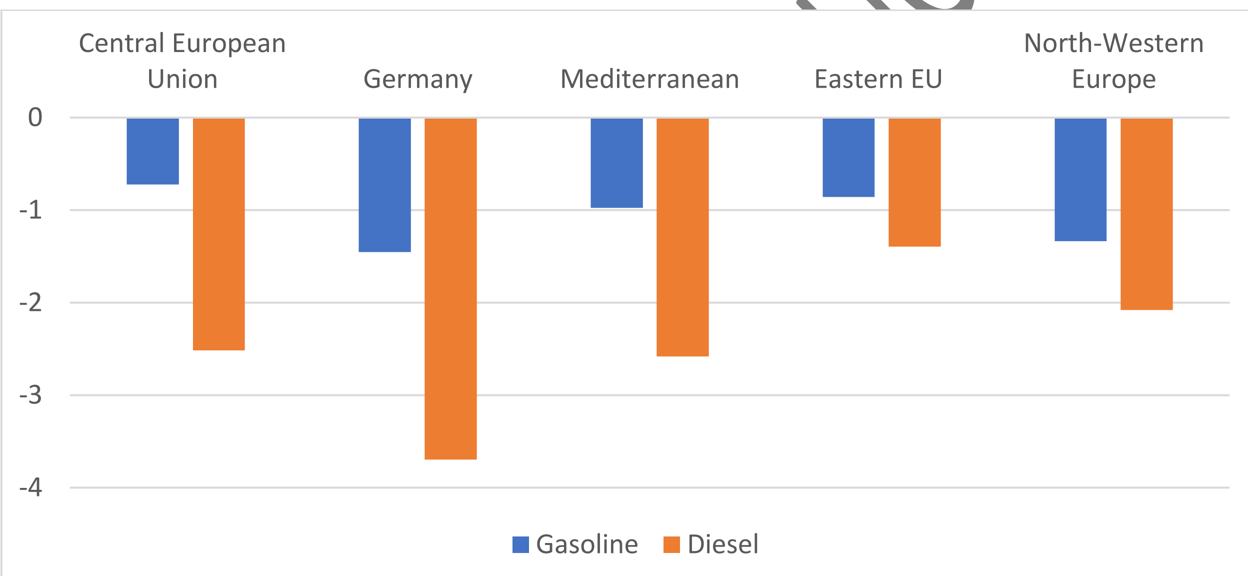
More broadly, we find that when removing the FFS, the quantity consumed of the previously subsidized energy goods in the regions implementing the FFSR drops by more than production. In combination with imports shrinking by more than exports, it reflects the diversion of some production to the world market. 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 FSSR. 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.

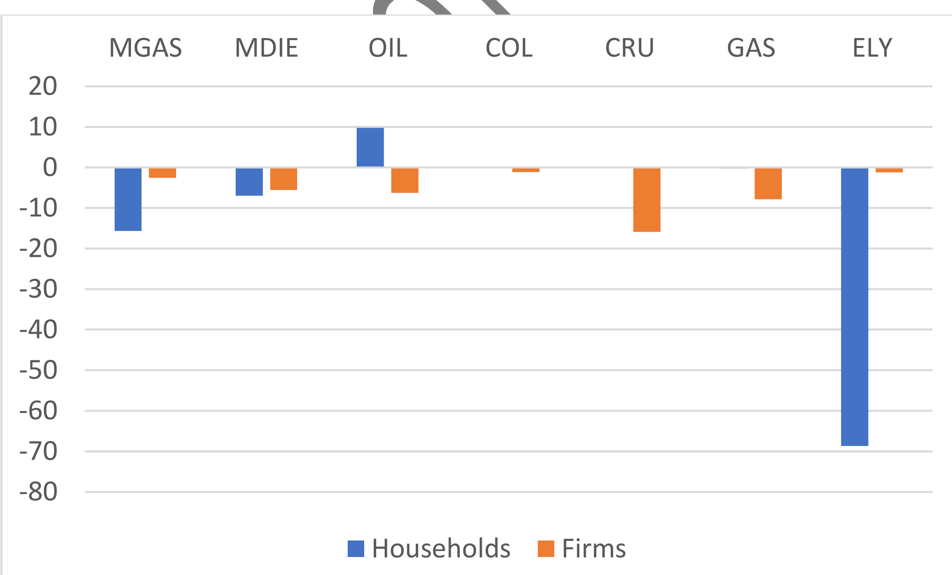
3.2 Impacts on non-subsidized fossil fuels

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-subsided 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 chemicals (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.

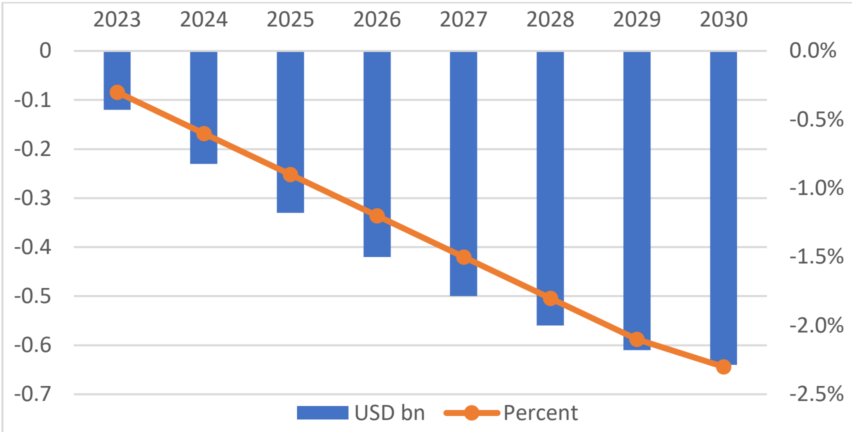
As expected, like for subsidized goods, the EU biofuel mandate has little impact on non-subsidized commodities outside of where it is implemented. We do nevertheless find that their consumption tends to increase as a result of the impact of the quota on international markets. In the EU where the biofuel 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 FFFSR 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.

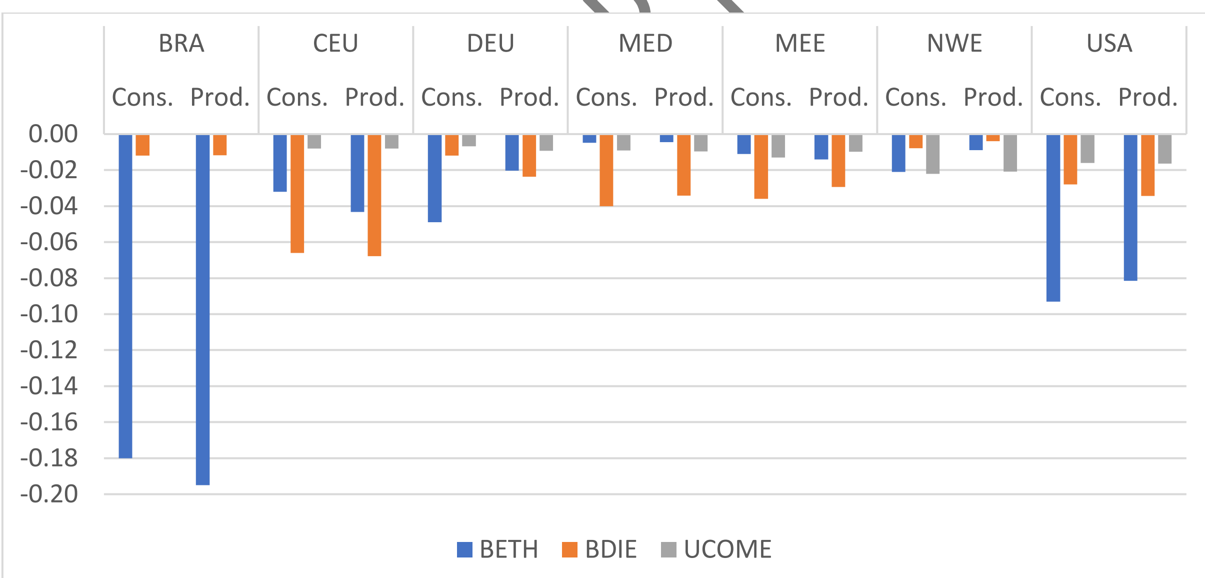
This increase in the import of biofuels in the subsidy reform's regions occurs as the consumption in the rest of the world drops. This is the result of biofuels becoming relatively cheaper compared to fossil fuels where subsidies were removed while becoming relatively more expensive outside of the subsidy 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 FSSR 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

	CEU	DEU	MED	MEE	NWE	total
BETH	0.08	0.18	0.03	0.07	0.19	0.56
BDIE	0.33	0.43	0.32	0.13	0.20	1.42
UCOME	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 categories[13] 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

[13] As per table 2

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 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 terms 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 FSS 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 (Saunder & 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 coincidently 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 2020[14]. 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 shrink. It is event 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 bellow supply cost. Ideally, we would explicitly model and quantify the impact of all form of fossil fuel subsidies (not only the one observes by the price-gap approach, as well as on production, production factors, ect) 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. Approach 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.

[14] annex_to_the_state_of_the_energy_union_report_on_energy_subsidies_in_the_eu.pdf (europa.eu)

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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%)