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Phasing out palm and soy oil biodiesel in the EU: What is the benefit?

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Abstract

The Renewable Energy Directive (RED II) by the European Union (EU) provides an updated framework for the use of renewable energy in the EU transport sector until 2030, and bans the use of biofuels with a high risk of causing indirect land-use change in high carbon stock areas (high ILUC-risk criteria). The only biofuel feedstock affected by this criterion is palm oil. We employ the computable general equilibrium (CGE) model DART-BIO for a scenario-based policy analysis and evaluate a phase-out of palm oil-based biodiesel, and an additional phase-out of soy oil-based biodiesel in the EU. Our results show that the palm phase-out has only a relatively small impact on global palm fruit production and total crop land use in tropical and subtropical regions, while the soy phase-out leads to a comparable stronger decrease in global soy production, and a reduction in total cropland use in soy-producing regions. Both policies lead to increased oilseed production in the EU. Therefore, farmer in Malaysia and Indonesia face a significantly reduced income. While European farmers profit the most, EU firms and households are confronted with higher expenditures. Finally, this study indicates that unilateral demand-side regulations for a single good in a single sector is not sufficient for effective environmental protection. Enhanced binding sustainability criteria and certification schemes for the use of all vegetable oils in every sector and industry as well as improved protection schemes for sensible forest areas are necessary.

KEYWORDS

biofuels, computable general equilibrium (CGE), land use, palm oil, renewable energy directive (RED II), soy oil

1 | INTRODUCTION

Global biofuel production has experienced strong growth over the last decade (IEA, 2013, 2017). This was largely driven by climate mitigation policies, especially in the European Union (EU) and the United States of America (USA). After aiming for a 10% share of biofuels in total transport fuels by 2020, as defined by the Renewable

Energy Directive that came into force in 2009 (RED I) (European Union, 2009), the EU has recast the directive for the period 2020–2030 (RED II) in 2018 to correct for trade-offs with respect to food security and biodiversity caused by direct and indirect land-use change (European Union, 2018). The new legislation limits the share of biofuels and bioliquids produced from cereals and other starch-rich crops, sugars and oilseeds counting towards the mandate promoting the use of non-food crops for biofuel production. Moreover, the delegated regulation of the directive categorizes palm oil-based biodiesel as biofuel with a high risk of causing indirect land-use change (ILUC), and thus phases it out from the EU biofuel market from 2022 onwards to reach a zero subsidy by 2030 (high ILUC-risk criteria).

In the scientific debate, the role of biofuel production in direct and indirect land-use change, and deforestation remains controversial (Arima et al., 2011; Broch et al., 2013; Klein Goldewijk et al., 2017; Zilberman, 2017). Concerns about the potential negative effects of biofuel policies were already raised by Rosegrant et al. (2008) who estimated an increase in global demand for cropland. Hellmann and Verburg (2010) conclude that indirect land-use change effects of biofuel policies on biodiversity are greater than direct effects. Since then, various studies employed computable general equilibrium (CGE) and partial equilibrium (PE) models to estimate the global land-use effects of biofuel mandates (e.g. Calzadilla et al., 2016; Hertel & Beckman, 2011; Laborde, 2011; Laborde & Valin, 2012; Valin et al., 2015; Zhang et al., 2013).

In this paper, we assess the implications of the high ILUC-risk classification of specific crops on agricultural markets and land use, by employing the global CGE model DART-BIO (**D**ynamic **A**pplied **R**egional **T**rade-**BIO** model). The only crop being affected by high ILUC classification is palm fruit. The EU has claimed that the ban on palm oil-based biodiesel is necessary to avoid deforestation and ILUC. The argument implies that the restriction of palm oil-based biodiesel in the EU should lead to lower palm oil production to avoid additional land-use change. While European farmers, biofuel producers and environmental associations welcome the policy (COPA/COGECA, 2018; EJF, 2019; NABU, 2019), palm fruit-producing countries criticize the regulation as a technical barrier to protect European oilseed producers (CPOPC, 2020; MITI, 2019; WTO, 2019). Especially Malaysia and Indonesia (MAI) which supply about 85% of global palm oil production (FAO, 2020) are strongly opposing the high ILUC-risk classification, which is currently subject to World Trade Organisation (WTO) disputes (WTO, 2019).

The regulation also appears controversial because other crops than palm fruit are not classified as high ILUC-risky, even though Brazilian soybean exports to Europe heavily contributed to deforestation (Rajão et al., 2020). Therefore, some European countries, such as Belgium, France and Italy, have already planned to ban soy oil from being used as biofuel feedstock as well (Brussels Times, 2021; Canopée, 2020; Legambiente, 2021). As a consequence, also the EU is rethinking their sustainability criteria for RED II (European Commission, 2021), and political groups of the EU parliament handed in proposals to classify soy oil as high ILUC-risky (EURACTIV, 2022). Finally, in summer 2023, the EU has introduced the regulation on deforestation-free products (EUDR), according to which traders of several commodities including those based on palm fruit and soy will have to prove that these products are deforestation free (Regulation (EU) 2023/1115). The regulation will come into effect early 2025, but is not such a strict rule with respect to banning particular products from EU markets as the ILUC criteria in the RED II and again focuses on a limited number of commodities.

The aim of our study is to analyse the effects of the EU firstly phasing out the use of palm oil-based biodiesel and secondly additionally phasing out soy oil-based biodiesel on agricultural markets and land use. As a result, we show whether the current high ILUC-risk classification can be considered an effective measure for the urgently required protection of valuable forests and wetlands. Moreover, we compare this to the effectiveness of the likely future scenario of classifying soybeans as high ILUC-risk feedstock as well.

Only a few economy-wide studies (see below) specifically address the impact of the restriction on palm oil-based biofuels, and to the best of our knowledge, we are the first to model the phase-out of soy oil-based biodiesel in the EU.

Philippidis et al. (2018) make use of the MAGNET model to run a scenario-based analysis of reform proposals of the RED II, including a reduction of palm oil-based biodiesel. According to their model results, the reduction results in lower biodiesel and higher bioethanol production in the EU, as well as fewer vegetable oil imports from Asia and more production of oilseeds in the EU, while global total oilseed production increases. Their approach faces three limitations. First, as also acknowledged by the authors, in their evaluation palm oil imports may be reduced too much due to approximations considering the vegetable oil trade. Second, given the aggregated oilseed sectors, the authors are unable to track substitution effects between different oilseed oil types in biofuel sectors. Third, it remains unclear how it is assured that biodiesel imports into the EU are not based on palm oil.

Taheripour et al. (2019) and Busch et al. (2022) model restrictions in palm oil production for Malaysia/Indonesia (MAI). Taheripour et al. (2019) employ the CGE model GTAP-BIO and assume domestic taxes in MAI, or global import tariffs for palm oil depending on their scenario. They conclude that concentrating restrictions only on one crop, and thereby only on one driver of deforestation, leaves room for other drivers that step into place, limiting the overall effects of restricting palm fruit production for stopping deforestation. Furthermore, they note that reducing palm oil production leads to a global demand shift towards other vegetable oils, increasing the production of other oilseed crops. Their results are in line with the findings of Philippidis et al. (2018).

Busch et al. (2022) differentiate between high- and low-deforestation palm oil in Indonesia to model the land-use and emission effects of banning the use of high-deforestation palm oil by various regional groups, including the EU. They employ a linkage of the CGE-Model GTAP-BIO and the regional land-use model OSIRIS. According to them, over 60% of the EU palm oil imports from MAI are high-deforestation palm oil. Thus, banning high-deforestation palm oil in the EU causes a 54% reduction in total palm oil imports from this region, while the low-deforestation palm oil imports increase by 31%. The authors summarize that this policy leads to 1.6% less deforestation compared to the baseline, as high deforestation palm oil is then traded to other regions. Therefore, they report a larger price premium for low-deforestation palm oil (Busch et al., 2022).

This study adds to the literature on two levels. First, in contrast to Taheripour et al. (2019) and Busch et al. (2022), we do not model a hypothetical scenario, but a concrete policy that has been put in place by the EU. Thereby we do not only evaluate the effects of the policy on deforestation pressures in MAI, but we also look at global substitution and price effects and evaluate which region may economically benefit from this policy. By implementing a specific palm oil biodiesel sector, we avoid the above-elaborated simplification of the study by Philippidis et al. (2018). Second, we analyse the additional phase-out of soy oil-based biodiesel, which has not yet been quantified in the literature. Compared to palm oil, the soy oil-based biodiesel phase-out not only affects different regions, but may also have different implications on land use, as soy is an annual crop, and not a perennial crop like palm fruit.

2 | MATERIALS AND METHODS

2.1 | The DART-BIO model and data sources

As examined in the literature review, CGE models have often been used to study the impacts of biofuel policies. This is because they are powerful tools when it comes to tracing policy effects on product and factor markets, as they encompass the complete circular flow of income in an economy through linkages in factor markets as well as in production and consumption. In addition, global CGE models capture trade flows in the world economy and can thus depict feedback effects of highly integrated agricultural markets on land use in various regions. For our analysis of the RED II, we employ an updated version of the DART-BIO model, a multi-sectoral, multi-regional recursive dynamic CGE model of the world economy with a detailed representation of the biofuel industry and global land use (Calzadilla et al., 2016; Delzeit, Klepper, et al., 2018; Klepper & Peterson, 2006; Springer, 1998). Table A1 in the Appendix S1 shows our regional aggregation featuring 21 regions with a focus on big global biofuel producers such as the USA, MAI and the EU. Similarly, our sectoral disaggregation with 48 sectors, as shown in Table A2 in the Appendix S1, considers the different stages of biofuel production in detail with the major biofuel feedstock crops, biofuels and by-products.

The DART-BIO model is based on the GTAP9 database (Aguiar et al., 2016). Following Calzadilla et al. (2016), the model includes bioethanol production from sugar cane/beet, wheat, maize and other grains; and biodiesel production from palm oil, soybean oil, rapeseed oil, used cooking oil (UCO) and other oilseed oils. DART-BIO explicitly accounts for the by-products generated during the production process of different vegetable oils and biofuels. Dried distillers grains with solubles (DDGS) are byproducts of the production of bioethanol from grains and oilseed meals/cakes are by-products of different vegetable oil industries. The production shares of DDGS and oilseed meals are presented in Table A3 in the Appendix S1. Thus, unlike the standard GTAP database, we differentiate between production activities and commodities, which allows us to model joint production in the bioethanol and vegetable oil industry. Calzadilla et al. (2016) and Delzeit, Winkler, et al. (2018) find that differentiating different vegetable oils and their different shares of co-produced meals result in smaller price changes compared to models without these differentiations.

In this updated version, in addition to the biofuels in Calzadilla et al. (2016), we include a dedicated palm oil-based biodiesel sector to be able to implement the palm oil biodiesel phase-out unambiguously. The new sectors are split from aggregated sectors in the original GTAP9 database using splitting weights calculated from data sources such as COMTRADE, FAOSTAT and F.O. Licht. Details on the construction of the DART-BIO database as well as assumptions regarding production technologies are available in Delzeit et al. (2021).

Unlike palm oil, soy oil-based biodiesel was not disaggregated from the biodiesel sector when constructing the DART-BIO database. In order to restrict the consumption of soy oil-based biodiesel in the EU for this study, a combination of constraints on production and exports was implemented. For this purpose, soy oil used in EU biodiesel production was modelled into a Leontief production nest separate from other intermediates. Outside of the EU, the 2019 shares of biodiesel produced from soy oil were calculated using data from the USDA and EIA (EIA, 2021; USDA Global Agricultural Information Network (GAIN) reports, 2015–2021h). These were assumed to be constant after 2019, identical across export destinations and between domestic and export markets to estimate soy oil-based biodiesel trade in the following years.

The economy in each region is modelled as a competitive economy with flexible prices and market clearing conditions. The economic structure of DART-BIO is fully specified for each region and covers production, investment and final consumption by a representative consumer and the government. Private consumption is maximized according to a Stone–Geary utility function (Stone, 1954), while multi-nested constant elasticity of substitution (CES) functions determine substitution between production factors and energy in the production sectors. Other intermediate inputs enter the production of commodities subject to fixed input–output relations. Assuming that labour and capital are homogeneous goods, they can move across industries within regions, but cannot move internationally. Apart from capital and labour as individual factor inputs, the land is disaggregated into 18 different land types according to the length of the growing period and climatic zone. Thus, we include not only land-use heterogeneity in agriculture and forestry, but these agro-ecological zones (AEZs) also cover land heterogeneity in each region (Baldos, 2017; Lee et al., 2005). Land mobility between sectors is governed by constant elasticity of transformation (CET) functions. DART-BIO applies a three-level nesting structure, where land is first allocated agriculture and managed forest. In the second nest, agricultural land is allocated between pasture and crops. At the next level, cropland is allocated between rice, palm, sugar cane/beet and annual crops (wheat, maize, rapeseed, soybeans, other grains, other oilseeds and other crops nec). At each level, the elasticity of transformation increases, reflecting that land is more mobile between crops than between forestry and agriculture. Transformation elasticities are taken from OECD (2001). An extensive modelling comparison by AgMIP (Schmitz et al., 2014) reveals that identifying transformation elasticities in CGE modelling is challenging due to the lack of conclusive empirical evidence. The CET function concerns land-use change within managed land. Some models include an endogenous expansion of agricultural and forestry activities into unmanaged areas governed by land supply functions (e.g. Banse et al., 2008; Philippidis et al., 2018), while other model apply scenario-based expansion (e.g. Zabel et al., 2019).

Trade between regions happens under the Armington assumption of imperfect substitution between imported and domestically produced commodities. The numeraire region is the USA. Investment in each region is determined by fixed private marginal propensities to save, but fast-growing regions' saving rates converge to those of industrial countries. The model is recursive dynamic and is solved for a sequence of static annual equilibria for periods from 2011 to 2030. Over this period, we calibrate the model to match regional GDP growth projections of the OECD (2018a) via adjustments of labour productivity and update key parameters between the model runs. The capital stock available for the next period is updated with the current period's investments and depreciation, while labour supply changes according to regional workforce and population growth projections OECD (2018b).

2.2 | Definition of scenarios

To capture the potential impact of the phase-outs of particular biofuel feedstocks on agricultural markets, we define three different scenarios until 2030. Table 1 gives an overview of these scenarios which are described in detail below. The different mandates are implemented within the scenarios via a binding quota on composite consumption. Practically, this quota is implemented as a negative endogenous tax on consumption.

TABLE 1 Scenarios.

	Biofuel policies		
Name	**Feed- and food-based biofuels**	**Palm oil-based biodiesel**	**Soy oil-based biodiesel**
RED II **N**o **P**hase-**O**ut (NPO)	7% of total consumption in transport sector are reached until 2030	No restriction	No restriction
RED II **P**alm oil **P**hase-**O**ut (PPO)	7% of total consumption in transport sector are reached until 2030	Consumption share in total transport sector reduced to 0% between 2022 and 2030	No restriction
RED II **P**alm and **S**oy oil **P**hase-**O**ut (PSPO)	7% of total consumption in transport sector are reached until 2030	Consumption share in total transport sector reduced to 0% between 2022 and 2030	Consumption share in total transport sector reduced to 0% between 2022 and 2030

2.2.1 | RED II No Phase-Out (NPO)

The EU RED II stipulates a 14% share of renewables in total transport fuel consumption until 2030 and a provisional agreement is aiming to increase the target to 29%. In the *RED II No Phase-out s*cenario (*NPO*) we assume that member states meet this renewable energy target in the transport sector with the maximum allowable share of biofuels according to the RED II. This means that the share of feed- and food-based biofuels is gradually increased to 7% for bioethanol and biodiesel individually, and changes in biodiesel feedstock prices lead only to substitution within the biodiesel feedstock pool. It is known that member states may impose a stricter limit that would lower consumption below the 7% simulated. However, no specific values are yet communicated and choosing a different limit would therefore imply making additional assumptions. With the limit on 7% our result can be considered to show the upper benchmark of effects.

In this scenario, we do not assume a phase-out of any biofuel feedstock, as this scenario provides us with the baseline to evaluate the effects of a phase-out of palm and soy oil-based biodiesel.

2.2.2 | RED II Palm oil Phase-Out (PPO)

In this scenario, we implement the same assumptions as in *NPO* but apply the restriction on biodiesel from palm oil. This means that the maximum share of conventional biodiesel of 7% is still met until 2030, but that palm oil-based biodiesel is gradually phased out from 2022 until it is completely banned in 2030. The share of palm oil-based biodiesel must be replaced by other types of biodiesel. The scenario design enables us to investigate whether the EU's strategy to ban palm oil-based biodiesel is effective in reducing ILUC and thus land demand in palm oil-producing countries, or whether the palm oil restriction functions without reducing deforestation pressures.

2.2.3 | RED II Palm and Soy oil Phase-Out (PSPO)

In addition to the assumptions of the *PPO* scenario, this scenario simulates the additional phase-out of soy oil-based biodiesel, by gradually restricting soy oil that enters the biodiesel production in the EU starting in 2023 until none enters the sector by 2030. In addition, the import of biodiesel from countries that produce biodiesel from soy was restricted based on production shares from USDA and EIA data (EIA, 2021; GAIN, 2015–2021h).

3 | RESULTS

3.1 | Biofuel and agricultural markets

In the discussion of the results, we compare the two phase-out scenarios for biodiesel feedstocks to the reference scenario. Figure 1 shows the share of different feedstocks used for biodiesel production in the EU in the respective scenarios. With no restriction, palm and soy oil account for about 36% of the biodiesel feedstock. When palm oil is phased out in the PPO scenario, the share of rapeseed oil increases the most, followed by increased use of other oilseed oils and soy oil. In the PSPO scenario, where also soy oil is phased out, rapeseed oil fuels nearly half of the European biodiesel production. In addition, the share of other oilseed oils increases, which leads to almost doubling of oilseed oil imports (1.7 bill. USD in PSPO) from the former Soviet countries (FSUs), where Ukraine is the major producer of sunflower oil. These results do not account for the increased price volatility and supply risks due to the Russian war on the Ukraine. Berndt et al. (2022) shows

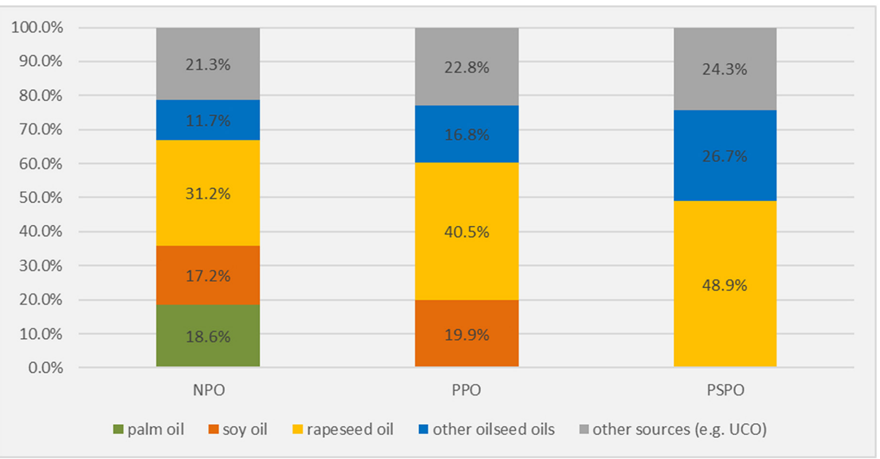

FIGURE 1 Biodiesel feedstock shares in the EU in 2030.

the impacts of the war on global agricultural markets, including the vegetable oil sector.

Figure 2 shows the changes in global and regional production and prices of oilseeds. In the PPO scenario, our results show an increase in global rapeseed prices which is driven by the increased demand and prices for rapeseed in the EU. In other regions, besides Russia (RUS) and the FSU, the rapeseed prices remain stable, and in some regions even decrease (<1%). Looking at rapeseed production, the largest increases occur in the EU, RUS and FSU. EU imports of rapeseed and rapeseed oil from RUS and FSU increase, and the EU becomes a net importer for both commodities, as displayed in Figure 3 in the next section.

Soybean production increases by only 0.1% in the PPO scenario, caused by increased demand for soy oil-based biodiesel in the EU. Soybean prices remain stable in this scenario. The prices decrease strongest in the case of palm fruit in MAI (−9.8%) and in Sub-Saharan Africa (AFR) (−5.4%). This is caused by a decrease in demand in the EU by phasing out palm oil-based biodiesel, which takes place in both scenarios, PPO and PSPO. Therefore, in MAI, while palm fruit production is 1.8% lower, land prices decrease and other oilseed production (such as coconut) that is consumed by the food and chemical industry, increases by about 9% compared to the baseline. The prices for other oilseeds do not change in this region.

When phasing out soy oil-based biodiesel in the PSPO scenario, increase in rapeseed production in the EU is double as high as in the PPO scenario. Thus, this policy affects rapeseed production similar to phasing out palm oil-based biodiesel. However, in addition to increasing rapeseed production, also the production of other oilseeds is increased by 4.2% in the EU. Thus, total oilseed production in the EU is stronger affected by the PSPO scenario than by the PPO scenario.

Soybean production decreases in the PSPO scenario in the USA, Brazil and the PAC region (Paraguay, Argentina, Uruguay, Chile). This is because total EU consumption of soy oil in PSPO is reduced by more than 50% (equivalent to 9%

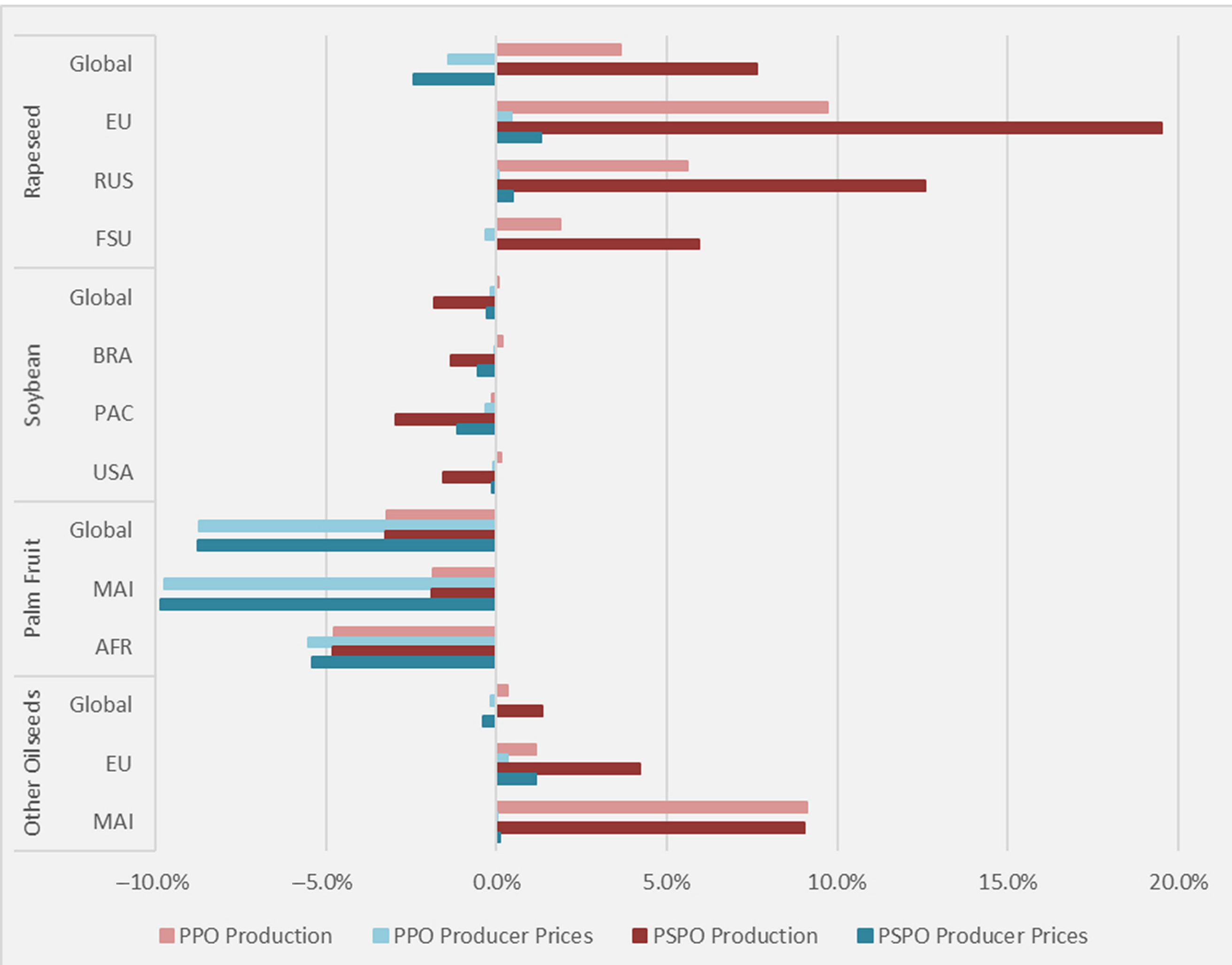

FIGURE 2 Production and producer prices for oilseeds in selected regions. Percentage change to NPO scenario in 2030.

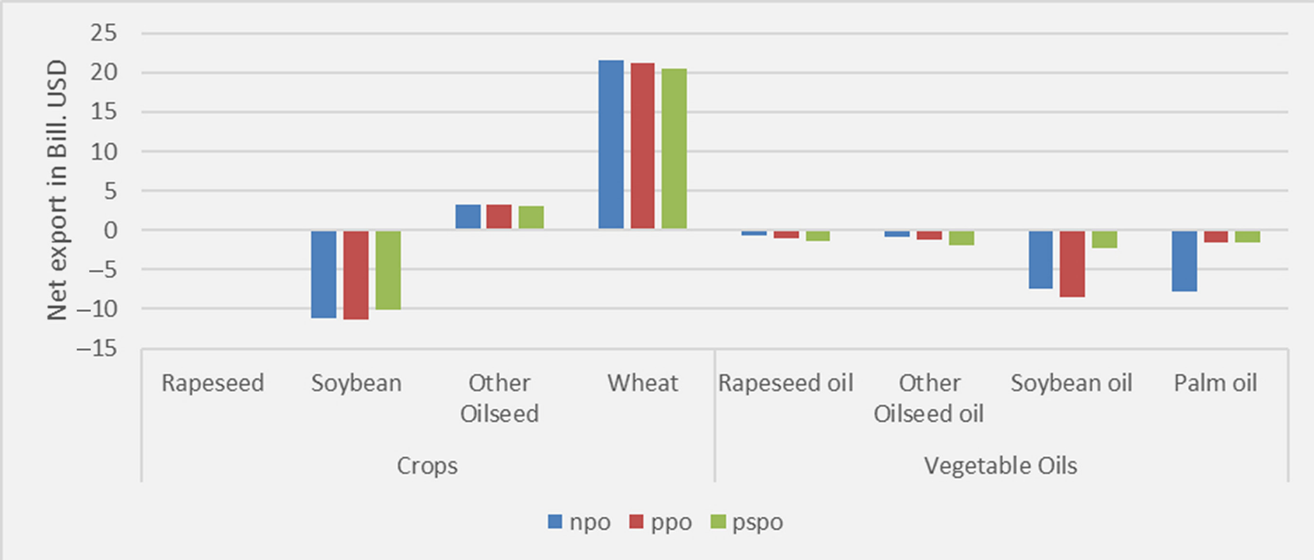

FIGURE 3 EU net exports in Billion USD.

of global consumption) compared to the baseline, in which soybean oil became almost as important for biodiesel production in the EU as palm oil until 2030 (see Figure 1). Even though demand for soybean meal from the livestock sectors is the most important driver of soybean production, the demand shock in PSPO is large enough to drive down world market prices for soy oil and to trigger production reactions. However, the relative reduction in soybean prices is lower than the reduction in production. Soybean is an annual crop, and soybean farmers can relatively easily adjust the planted area to changes in demand. In DART-BIO this is governed by the CET function (see Section 3.1). In contrast, palm fruit is a perennial crop such that higher price changes are needed to change land use compared to annual crops. With falling demand, land prices decline such that also producer prices decrease. Moreover, the regions of palm fruit production in South-East Asia are not typically used or suitable for rapeseed or soybean cultivation. Therefore, palm fruit is also the only crop for which the relative reduction in price, caused by the phase-out, is larger than the relative reduction in production. This is especially the case for MAI where palm fruit production is more competitive than in AFR. It is important to note, that compared to the scenario base year (2019), palm fruit area expands in every scenario, but less under the PPO and PSPO scenario compared to the baseline.

3.2 | Implications on global trade

The simulated changes in the EU's demand for biodiesel affect global trade in several ways. Figure 3 shows the EU's net exports of agricultural commodities for the respective scenarios. As previously mentioned, the EU becomes a net importer of rapeseed in the PPO scenario. Also, the net exports of other oilseeds and wheat decrease, and the net imports for all vegetable oils besides palm oil increase. The imports of palm oil drop as a result of the phase-out of palm oil-based biodiesel. The remaining palm oil imports are predominantly used in the food sector.

Looking at the impacts of the PSPO scenario, soybean and soybean oil imports into the EU decrease. For the other commodities, the effects already seen in the PPO scenario increase in magnitude. It is relevant to note that in the PSPO scenario, the increase in EU rapeseed production replaces domestic wheat production, which in turn leads to a reduction of the net exports by 4.5% compared to the baseline.

The scenario assumptions have feedback effects on bilateral trade patterns between the EU and those regions where the respective commodities are produced. Figure 4 displays the bilateral exports of vegetable oils by destination from major producing regions. The trade effects reflect the changes in production as discussed in the previous section. The lower imports of vegetable oil of the EU from MAI in the PPO scenario (−75%) lead to 1.8% less palm fruit production in MAI, and cause an increase in vegetable oil exports from MAI to other Asian countries (+12%). Therefore, these countries import less vegetable oils from South America and the USA. This effect is reversed when looking at the PSPO scenario. Due to the reduced soy oil imports to the EU, Asian countries increase vegetable oil imports from the American continent. However, Asian countries cannot absorb the soy oil that would have been traded to the EU. As elaborated previously, in contrast to palm fruit production in the palm oil phase-out, soybean production changes more when implementing a soy oil-based biodiesel phase-out. This is reflected in the trade values.

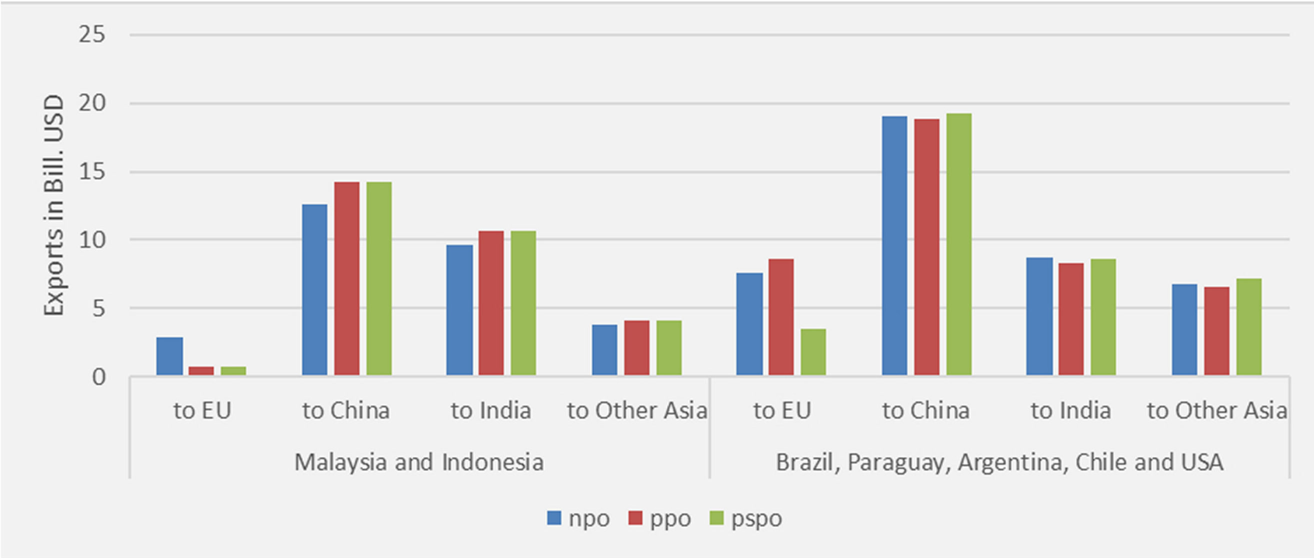

FIGURE 4 Bilateral exports of vegetable oils from major vegetable oil producing countries to major destinations.

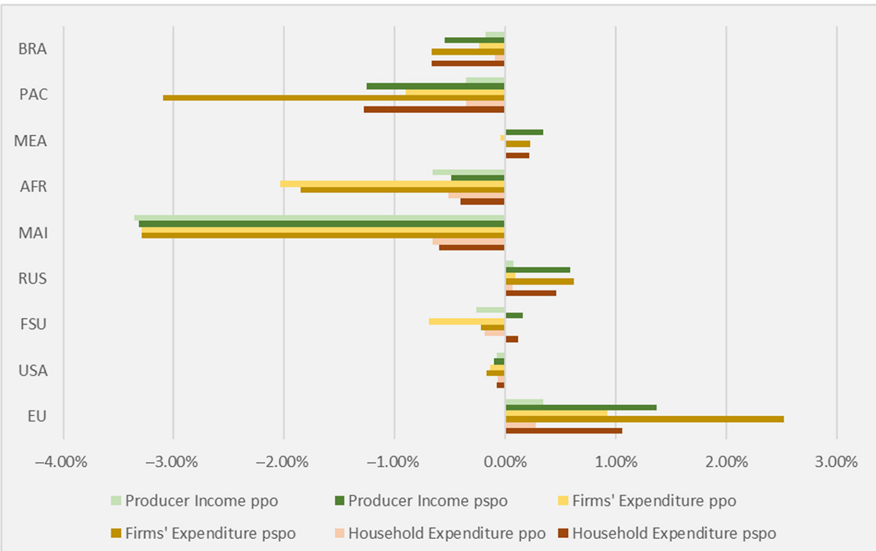

FIGURE 5 Producer income, firms' and household expenditure—all crop commodities aggregated. Percentage change to NPO scenario in 2030. Changes in household expenditure are very similar to changes in aggregated agricultural consumer prices.

3.3 | Implications for producers and consumers

Figure 5 provides an overview of regional agricultural producer income, firms' expenditure and household expenditure, aggregated over all crop commodities. It can be noted that changes in household expenditure are similar to changes in the aggregated consumer price index for agricultural commodities, as total direct consumption of agricultural commodities remains constant across the scenarios. In the PPO scenario, changes in producer income, and household and firms' expenditures by under 1% appear in most of the regions, besides AFR, MAI and EU. Especially in MAI, farmers have an aggregated lower income of −3.4% with the palm oil phase-out. Firms' expenditure reduces by almost the same, driven by lower costs for the vegetable oil industry. Household expenditure in MAI, however, decreases by −0.7%. On the one hand, palm fruit is not directly consumed by households, and on the other, the expansion in palm fruit production is barely reduced in favour of other agricultural commodities that are directly consumed by households in MAI. Thus, price effects caused by lower palm fruit prices are transmitted to the palm oil sector whose products are: (1) not sufficiently consumed domestically to affect total household expenditure, (2) exported at lower prices and (3) used by industrial sectors where the price decrease has no noticeable effect on output prices.

We observe a different development in AFR, where in contrast to MAI palm fruit expansion is substituted by expanding other agricultural activities, and the reduction in producer income is comparable to the reduction in household expenditure. Firms profit from lower average agricultural prices, but also produce less due to lower palm oil production, leading to drop in expenditures by −1.9%.

Considering the PSPO scenario, in the EU we observe the largest gains for producers (+1.4%), a slightly lower increase in household expenditure for crops (+1.1%), but a stronger increase in expenditure for firms (+2.5%) due to higher commodity prices and the increased demand for rapeseed. The USA is only marginally affected (−0.1% to −0.2%) by the EU policies, though being a major producer of soybeans. In Brazil and PAC households benefit from lower prices in the PSPO scenario, and consumer gains in expenditure are higher than producer losses in income. Firms in PAC experience a reduction in expenditure for agricultural commodities (−3.1%), which is price driven as well. In the Middle East and North Africa (MEA), and AFR, we observe spill-over effects from other regions. While the increased production of rapeseed in the EU leads to increasing producer prices and household expenditure in MEA, in AFR this development reverses some of the effects from the palm oil phase-out, comparing the scenario PPO to PSPO.

3.4 | Implications for land use

The output adjustments in the two scenarios are mirrored by changes in land use. Figure 6 shows the change in harvested area by selected crop, region and scenario. In the EU the rapeseed area expands by about 800 thousand hectares in the PPO scenario. The additional rapeseed land comes at the cost of grain cultivation, as well as fruit and vegetable cultivation (other crops), which is not displayed here. The global soybean area increases in the PPO scenario, mainly in the USA and South America.

As already explained above, the scenario difference in palm fruit production is 3% on a global level. Conversely, phasing out palm oil in the PPO scenario leads to nearly three times higher land use by rapeseed and soybean production compared to the land spared by reduced palm fruit cultivation. One reason for this effect is the higher biodiesel yield per hectare of palm oil (~4400 L/ha) compared to rapeseed (~1775 L/ha) or soybean (~664 L/ha) (FNR, 2022). In 2018, 10% of global palm fruit output is used for biodiesel production which is mainly consumed in the EU, and the major palm fruit-producing regions are MAI (56% of global production in the reference scenario in 2030) and AFR (35% of global production). While the

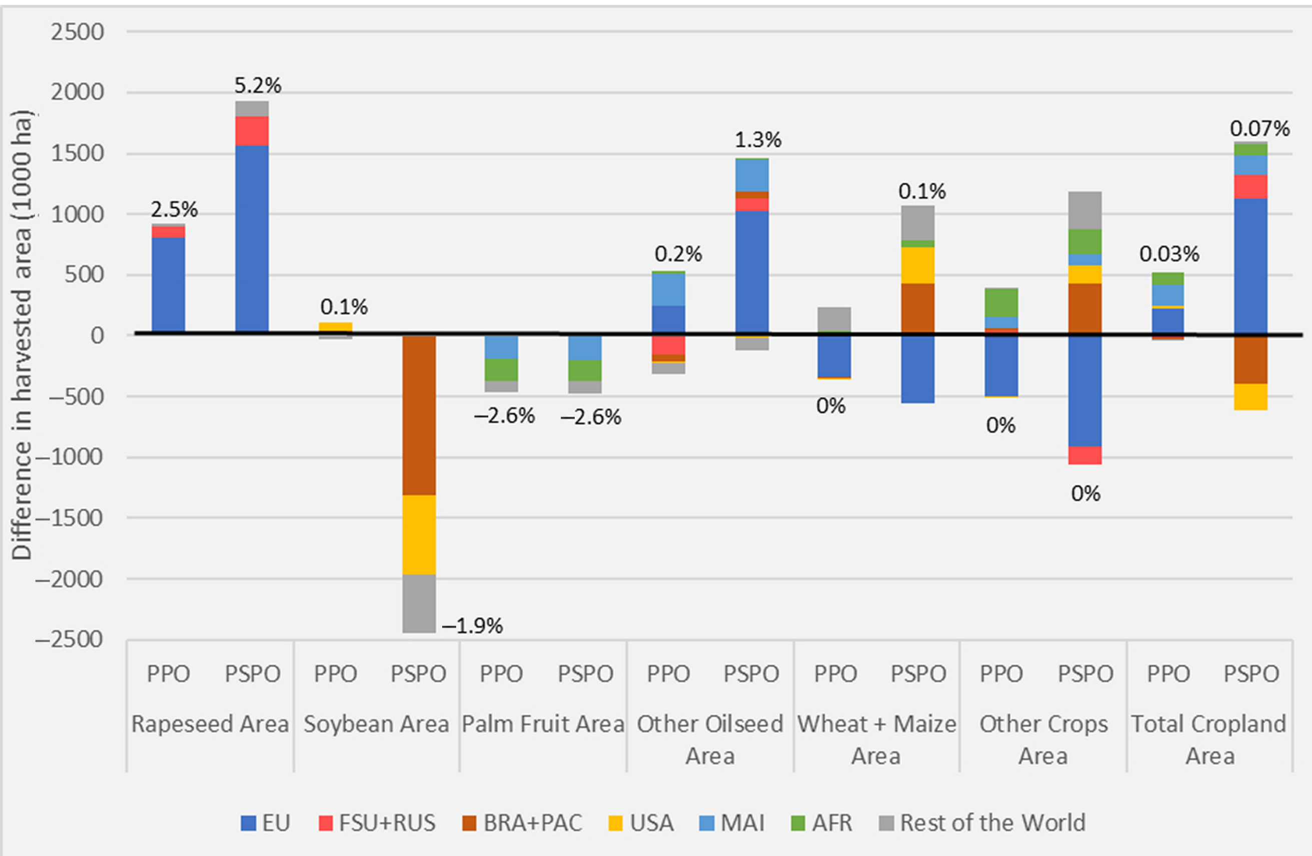

FIGURE 6 Change of harvested area under palm and soy oil biodiesel phase-out for selected oilseeds, food crops and total cropland. The percentage value indicates the relative global change compared to the global harvested area of the respective crops in the baseline.

palm oil-based biodiesel phase-out in the EU leads to globally 2.6% less palm fruit area in 2030, land used for palm fruit in MAI is only 1.7% lower compared to the baseline.

One reason why the effect on palm fruit production in MAI is lower compared to the global average is the cost advantage of palm fruit production compared to AFR and Rest of South America (LAM). As the price for palm fruit drops due to the palm oil phase-out, the production in those two regions differs stronger compared to the baseline (AFR: −3.7%, LAM: −8.3%). But also in AFR, more than the area spared by lower palm fruit expansion (176 t ha) is consumed by cultivating 'other crops' (AGR) (200 t ha). In the EU we see less cropland used for 'other crops' (312 t ha) due to more rapeseed production.

Compared to the PPO scenario, in the PSPO scenario, rapeseed area almost doubles in the EU, leading to less cultivation of grains. However, in absolute terms, the reduction in the global soybean area is larger than the increase in the global rapeseed area. Therefore, in the EU, the area for other oilseeds is additionally increased, overcompensating the area spared in Southern America and the USA.

Since Brazil, PAC and the USA are jointly responsible for 86% of the global soy production, most of the reduction of soybean area takes place in those three regions, where in turn more grains and other food crops are cultivated. In relative terms, however, we can see that phasing out soy oil biodiesel in the EU causes a soy production area change of −1.9% globally (−1.3% in Brazil, −2.9% in PAC, −1.5% in the USA). This means that in the PSPO scenario total cropland expansion is twice as high as in PPO, compared to the baseline. On the one hand, because soy oil is substituted by other oilseed oil and rapeseed oil. On the other, with lower prices for soy oil, the co-product soy meal becomes less competitive. The value share of meals when crushing soy is more than double the share of meals when processing rapeseed and triple the share for other oilseeds. Therefore, additional rapeseed, but also maize and wheat, is cultivated to substitute soy meal consumed by the livestock sector. However, from a global perspective the changes between the scenarios in total global cropland utilization are only marginal (<0.1%).

4 | DISCUSSION

When phasing out palm and soy oil as biodiesel feedstocks in the EU, biodiesel demand is predominantly met by rapeseed-based biodiesel. This leads to higher production quantities of EU-based rapeseed and rapeseed oil. EU's farmers can be considered to be beneficiaries of this policy since they generate additional revenues due to expanding the production of rapeseed while simultaneously obtaining higher prices. In turn, they produce fewer grains and other annual crops. Nevertheless, impacts on the EU grain market remain small and prices increase by a maximum of 2% depending on the scenario and crop. In both scenarios, the EU increases imports of rapeseed and other oilseed oils (e.g. sunflower) from RUS and to a much larger extent from FSU (including Ukraine).

Considering the increasing relevance of oilseed production in FSU and RUS in the PSPO scenario, it must be kept in mind that market distortions due to the Russian war on Ukraine are not accounted for in the model. Thus, considering the current situation, we might underestimate the effect of the policies on global crop prices and land-use change. If the production from FSU and RUS is not available on the world market in the future, more oilseed production outside these two regions will be necessary to fuel the EU biofuel demand by 2030. Berndt et al. (2022) analyse the implications of the war in Ukraine for the EU biofuel sector, showing that in the long run, global adjustments in land use can take place to substitute the missing production from Ukraine and Russia.

Furthermore, our results show the relevance of differentiating between different oilseed crops and vegetable oils when analysing biofuel policies. Philippidis et al. (2018), who also specifically address the palm oil phase-out, do not find considerable impacts on the EU's crop markets, as they do not consider feedback and substitution effects between vegetable oils on domestic and global markets. Our results show that the phase-out of palm oil and soy oils biofuel feedstock changes the use of different vegetable oil types. In the case of phasing out palm oil only, more rapeseed oil and soybean oil are used for biofuels in the EU (+5 bill. USD), and palm oil and other oilseed oil from MAI is increasingly used in the chemical and food sectors of China and India (+2.7 bill. USD). On the other hand, considering that in future exporters to the EU have to prove under the EUDR that their palm oil-based products are 'deforestation free', the demand for the formerly certified palm oil is likely to be high. However, it remains unclear if this could in fact even increase the production of sustainable palm oil. In addition, Malaysia and Indonesia produce more other oilseeds whose production is not addressed by the policy.

These findings are in line with the claim that an unilateral palm oil phase-out for only one specific application is without substantial impacts on deforestation pressures. This model does not simulate endogenous land expansion into natural forests, which would be an important characteristic to assess deforestation magnitude and the related CO2 emissions. However, the DART-BIO model simulates land-use change on managed land (including pasture and managed forests) driven by crop demand and crop type specific land prices. As a result, it is possible to assess changes in the demand for land for palm fruit production under different scenario assumptions. In Sub-Saharan Africa, the difference in palm fruit production between the baseline and the palm oil phase-out scenario is larger than in Malaysia and Indonesia, and it can be assumed that the palm oil phase-out significantly decelerates the increase in palm fruit production in this area. But in turn, production of other crops increases, causing a marginal increase in total cropland use in Sub-Saharan Africa. Considering Malaysia and Indonesia, our results coincide with Busch et al. (2022). We find that the phase-out of palm oil as a biofuel feedstock in the EU has only a relatively small impact on the development of Asian palm fruit production, because of the deviation of global palm oil trade. Therefore, income effects for palm fruit producers (−9.7%) and the total agricultural sector (−3.3%) are not negligible. Also, we can show that EU's farmers are the primary beneficiaries by generating higher incomes (+0.4%).

The motivation of the EU for the phase-out is the protection of high carbon stock (hcs) land by reducing the increase in palm fruit production. Nevertheless, besides an increase in rapeseed production, our results show an increase in soybean production in particular in Brazil, Paraguay and Argentina. The European Commission's report on the status of production expansion of relevant food and feed crops worldwide (COM/2019/142) to identify high ILUC-risk fuels and certify low ILUC-risk fuels concludes that soybean production has a low risk of expansion into high carbon land. The EC's assessment focuses on the share of expansion of a biofuel feedstock on hcs-land and overall significance of the increase in the production area of the feedstock. However, the dynamics of deforestation in South America, particularly the Amazon, are complex. Studies suggest that, even though direct deforestation is mostly driven by the expansion of cattle ranching, such expansion can be statistically linked to the replacement of pastureland by soy production elsewhere in Brazil (Arima et al., 2011; Barona et al., 2010). Given increases in land prices, there is a considerable probability that a growth in soy production at least accelerates displacement dynamics causing expansion into hcs-land now in South America instead of South-East Asia.

To avoid these potential implications, we demonstrate that additionally phasing out soy oil-based biodiesel seems to be a suitable measure, as this policy causes larger reductions in soybean production in tropic and sub-tropic regions. In addition, when phasing out both biodiesel feedstock types, the global production of grains and other food crops increases. However, considering grain prices we need to take regional differences into account. While consumers in South America benefit from decreased soybean production and lower prices for agricultural commodities (−1.28%), countries of the EU face higher prices for these products (+1.06%) due to increased production of rapeseed and other oilseeds in the EU. Middle East and North Africa, and Sub-Saharan Africa are only marginally affected (+0.1%–0.2%).

The key factors for assessing the effectiveness of the policies are to consider the biofuel productivity of oilseed crops in terms of land use and to evaluate the carbon emissions caused by the land use. As shown above, our model results indicate that due to the palm oil phase-out and to meet the demand for biofuels, more than twice the area saved by reduced palm fruit cultivation is needed for additional soybean and rapeseed production. These findings lie below the range of results of other studies, thus we might underestimate the additional cropland demand when phasing out palm oil-based biodiesel. Debnath (2019) states that the biofuel yield for palm fruit is 4.45 mt/ha while it is 1 mt/ha for rapeseed and 0.36 mt/ha for soybean. In contrast, in their report for the European Commission, Valin et al. (2015) assume 1.7 times higher biofuel yield per ha for palm fruit compared to rapeseed, and five times higher yield compared to soybean. However, these values do not account for meal production from soybean and give a distorted view on overall crop productivity. For the RED II calculation of land expansion into hcs-land the European Commission chooses a productivity factor of 2.5 for palm fruit and 1 for rapeseed and soybean (European Union, 2019). Relating to the scientific studies, the productivity factor for soybean is debatable, considering that compared to rapeseed, soy is twice as productive in meal production, but half as productive in oil production and about three times less productive considering biofuel yield. Moreover, even though the deforestation dynamics are more complex in South America, given the absolute historic expansion of soybean production areas in the region and the studies suggesting a significant displacement of cattle ranching and range land into hcs-land, like in the Amazon Forest but also the Cerrado or the Chaco Forest (Arima et al., 2011; Barona et al., 2010; Lapola et al., 2010), it seems likely that the shift in biodiesel production from palm oil to soybean oil accelerates these displacement dynamics. It needs to be further investigated how, when taking emissions from these indirect deforestation effects into account, such a shift in production compares to the emissions from palm oil and thus by how much reduces global emissions from land-use change.

5 | CONCLUSION

In a nutshell, we show a shift in the production of oilseed crops from tropic and sub-tropic areas to Europe caused by the two phase-out scenarios. While our results do not imply total cropland savings from the palm oil policy in palm oil-producing regions, the soy oil policy actually let to less cropland use in South America and the USA. Our findings thus raise concerns if it is justified to have a palm oil biodiesel phase-out, but not a soy oil biodiesel phase-out as well. The results of this study indicate that policies should ensure the responsible production of any crop in sensitive and so-called high ILUC-risk, regions. Focusing only on one crop in a single sector, either with binding sustainability criteria or a ban on utilization leads to substitution effects that could even drive further land-use change. Therefore, we second the findings of Taheripour et al. (2019) and Busch et al. (2022) that demand-side policies are not sufficient to halt deforestation. Tropical forests might benefit more from enhanced binding sustainability criteria and certification schemes for the use of all vegetable oils in every sector and industry as well as protection schemes for sensible forest areas. The EUDR is thus an important step in the right direction. Since the regulation only focuses on a limited amount number of agricultural and forest commodities, including soy and palm oil as the only oilseed crops, the effectiveness of this policy remains to be seen.

AUTHOR CONTRIBUTIONS

Tobias Heimann: Conceptualization; data curation; methodology; software; visualization; writing – original draft; writing – review and editing. **Robin Argueyrolles:** Data curation; formal analysis; software; writing – review and editing. **Manuel Reinhardt:** Data curation; formal analysis; software. **Franziska Schuenemann:** Conceptualization; data curation; methodology; software; writing – review and editing. **Mareike Söder:** Conceptualization; data curation; writing – review and editing. **Ruth Delzeit:** Conceptualization; data curation; funding acquisition; methodology; project administration; software; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the results of this study are available from https://doi.org/10.5281/zenodo.10167448. The study is based on data from GTAP. Restrictions apply to the availability of these data, which were used under license for this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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