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Promoting extensive cattle production in the European Union has major implications for global agricultural trade and climate change

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Promoting extensive cattle production in the European Union has major implications for agricultural trade and climate change

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Abstract

This paper assesses the potential market-mediated impacts, including global Land Use Change (LUC) and GHG emissions, from increased subsidies to pastureland-based livestock sectors in the EU, through a "tax recycling strategy" simulated against a baseline under SSP2 up to 2030. The budget neutral increase in the level of pastureland subsidy rates in different Member States is achieved by a decrease in land subsidies to other cropping activities. We employ an integrated CGE-MRIO approach, in which we link a recursive dynamic version of the well-known GTAP-CGE model, called GTAP-RDEM to the FABIO MRIO. This approach allows to take advantages from both methods. FABIO offers better resolution with regards to agricultural sectors than in the GTAP database, while the combined use of this MRIO with a CGE model allows to consider price and income dependent feedbacks, required for policy analyses and long run assessments of changes in the global economy. Results show that the redistribution of land-based subsidies provokes significant changes in agricultural markets across the EU. Pastureland areas and cattle production increases in almost all EU Member States, whereas crop land and crop production decreases. The resulting increase in crop prices translates into reduced output of intensive animal production sector, mainly pig and poultry, which rely on concentrate feed to a larger extent compared to cattle. As a result of the decrease in cropland area and overall crop production in the EU, most EU countries increase imports of grain, oilseeds, and cakes from major agricultural producers, essentially soybean cake from Brazil and North America. This generates significant LUC and related GHG emissions that spill outside the EU, mainly in major feed exporters while some emission saving is observed at global level.

Keywords: Pastureland, Cattle, Land Use Change (LUC) and GHG emissions, CGE-MRIO approach
JEL classification:

1 Introduction

Population growth, rising incomes, as well as changes in dietary patterns and production technologies are identified as main drivers of increased global consumption of livestock products in the last decades (Machovina et al. 2015; Godfray et al. 2018; OECD/FAO 2019). Global production of meat increased to 337 Mt in 2019 (+44% compared to 2000) and milk production to 883 Mt in 2019 (+52% compared to 2000) (FAO 2021). This went along with a shift to a more intensive livestock production systems, which rely on housing and nutrients-rich concentrate feeding (Gilbert et al. 2020). Due to its high protein content, soy has become a major feed crop with around 70% of its global production being used for feed (Brack et al. 2016). At the same time, there has been a significant decrease in pastureland areas, by 40% between 1982 and 2006 globally (Bao Le et al. 2014). These trends are set to continue: global consumption of meat and dairy products are projected to rise by 40 Mt and 20 Mt (in milk solids equivalent), respectively, to the year 2028 relative to 2019 (OECD/FAO 2019). Further intensification of livestock production is also expected, to feed the growing world population. According to Friends of the Earth Europe (2018), global soy-cultivated area might increase significantly, to reach 141 million hectares in 2050, essentially in countries such as in Argentina, the United States (US) and Brazil.

In the European Union (EU), the projected increased demand for concentrate feed implies a greater dependence on imports of protein-rich crops (EEA European Environment Agency 2017). Around 17 Mt of crude proteins are imported currently every year, of which 13 Mt are soy-based, representing a self-sufficiency rate of only 5% (EC European Commission 2018). These imports are mainly sourced from Brazil, Argentina, and the US. Between 2005 and 2017, over 80% of tropical deforestation embedded in EU imports was directly linked to soy production; and associated with loss of carbon-rich ecosystems, either directly or indirectly, which provokes Greenhouse Gas (GHG) emissions (Fehlenberg et al. 2017; Escobar et al. 2020). Moreover, livestock intensification and substitution for traditional feedstuffs in the EU has led to unwanted loss of pastureland, e.g., by 12% from 1991 to 2017 in Germany (Umwelt Bundesamt 2018), with negative impacts in terms of soil quality, carbon sequestration and other ecosystem services, such as biodiversity conservation (van Swaay et al. 2015; Alliance Environment 2019).

Multiple instruments of the Common Agricultural Policy (CAP) address pastureland maintenance and promote domestic production of plant protein sources. The so-called “Greening measures” (EC European Commission 2013) are compulsory and comprise, for instance, the maintenance of permanent pasture in Member States and support to legumes production, as these count towards the required

Ecological Focus Area[1]. Legumes production can also receive additional support since 2014 within the Voluntary Coupled Support (VCS)[2] (EC European Commission 2015) and the European Soy Declaration (European Council 2017). In order to boost the EU green growth transformation towards a" climate neutral EU" by 2050, as set by the "Green Deal" (EC European Commission 2020), the CAP post-2020 reform further reinforces and extends such measures. For example, the European Commission (EC European Commission 2019) favours a shift from compulsory crop diversification to obligatory crop rotations, while strengthening the maintenance of permanent pasturelands. An EU "plant protein strategy" was also proposed to be adopted for the CAP post-2020 reform by the (European Parliament 2018). It asks for additional reforms to reduce dependency on protein imports and to increase production of plant-based proteins at the EU level, enhancing the role of pastureland in maintaining agricultural sustainability and ecosystem services. Although these measures are in general welcome by farmers, for example by the COPA-COGECA organization that gathers farmers and agri-cooperatives in Europe (Guyomard et al. 2020), other voices, for instance scientists and environmentalists, call for more ambitious actions to foster extensive livestock production systems in the EU (Dupraz and Guyomard 2019; Chemnitz 2019). One option consists in offering opt-in measures under the Pillar II of the CAP to compensate farmers for potential profit losses when shifting to more extensive animal farming or producing protein crops. Decoupled CAP support can otherwise translate into an expansion of mono-cultural and animal intensive production systems at the expense of extensive farming (Scown et al. 2020).

This study aims to assess potential market-mediated impacts, including global LUC and GHG emissions, from increased support to pastureland-based livestock sector in the EU, through a "tax recycling strategy". This strategy implies a budget neutral increase in pastureland subsidy rates, differentiated by EU Member State, which is compensated by a decrease in land subsidies to other cropping activities. Such a redistribution of payments could strengthen the role of the CAP in preserving pastureland area and improve the environmental sustainability of the EU livestock sector. The internal redistribution of subsidies avoids an increase in the overall EU budget and fosters the substitution of cropland by pastureland. To the best of our knowledge, this is the first study to tackle both global direct and indirect effects from such a "Tax recycling strategy" which promotes a shift to more extensive

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[1] Farmers with more than 15 ha of arable land are obliged to dedicate 5% of this land to areas beneficial for biodiversity, i.e., Ecological Focus Areas (EFA), such as trees, hedges and land left fallow, which can improve biodiversity and safeguard natural habitats (EC European Commission 2013).

[2] Although CAP income support has been progressively decoupled, EU countries can still link limited payments (up to 8% of total income support budget, with a possibility of higher budget share under certain conditions) to specific agricultural sectors and products, which are considered as important for social, economic, and environmental reasons. Example of these eligible sectors include cereals, protein crops and grain legumes (EC European Commission 2015) .

livestock production in the EU. The results could inform the design of the future CAP, especially by highlighting the interaction between improved the environmental efficiency of CAP payments in the EU and global spillovers up to the year 2030.

2 Review of the literature: Quantitative assessment of the environmental sustainability of the EU livestock sector

Recent literature has assessed environmental impacts from the European livestock industry quantitatively, by applying a broad range of methods, scopes, and perspectives. Live Cycle Analysis (LCA) is widely used for detailed environmental assessments of specific agri-food processes or supply chains. It quantifies in detail resource consumption and emissions along the entire life cycle to measure associated environmental impacts “from cradle to grave”. LCA has been applied, for instance, to calculate water and carbon footprints of meat and dairy production in different geographical contexts (Buratti et al. 2017; Presumido et al. 2018). However, LCA is unable to simulate behavioural responses to market and policy signals. Here, farm-level economic optimization models are frequently used to assess the environmental performance of EU livestock production (Janssen et al. 2010). For instance, Murphy et al. (2017) employ the Grange Dairy Beef Systems Model (GDBSM), a bottom-up farm model, to investigate the GHG emission efficiency of beef production systems in Ireland. Heinrichs et al. (2021) use the bio-economic model FarmDyn to evaluate economic and environmental impacts of policies promoting legume production in France and Germany. Such bio-economic models capture in detail the production technology and related farm management decisions, but require quite comprehensive data and are therefore mainly used for smaller case studies (Ciaian et al. 2013; van der Linden et al. 2020). The majority of these studies focus on domestic impacts only, ignoring technology or policy spillovers (Gocht et al. 2016). A recent study by Britz et al. (2021) starts from a review of four bio-economic farm models (CAPRI- FT, FARMDYN, FSSIM, IFM-CAP) to provide a design for a modular and generic modelling tool. While such a model design gives more flexibility in agricultural assessments, e.g., in terms of farm management systems, regional cover, and policy measures, the challenge remains that supply models are unable to predict market feedback or regional spillovers.

To address this, larger economic models are applied to analyse effects across global agri-food sectors (Valin et al. 2014; Wiedmann et al. 2007). Such analysis either draws on multi-region input output (MRIO) analysis or employ global economic equilibrium models, of the General Equilibrium (CGE) or Partial Equilibrium (PE) type. MRIO represents an extension of the well-known input-output (IO) analysis, also called Leontief analysis (Leontief 1970). In MRIO, intermediate input demand of each sector is differentiated by product and country of origin, thus capturing bilateral trade, and combined with environmental extensions. The underlying global databases combine IO tables from different countries and regions with trade statistics, describing the structure of production technologies and the monetary and/or physical flows of goods and services within the economy (Murray and Lenzen

2013). Examples of widely-used MRIO databases are EXIOBASE (Tukker et al. 2013) and EORA (Lenzen et al. 2012; Lenzen et al. 2013), which include environmental extensions for the estimation of both emission and resource footprints. These have been used, for instance, by Beylot et al. (2019), Sun et al. (2020) and Koslowski et al. (2020) to trace global supply chains of primary crops and livestock products and quantify the EU’s global environmental footprint from total food consumption including meat and dairy products. However, MRIO analysis assumes constant IO coefficients (i.e., constant resource conversion efficiencies) and does not consider resource constraints, which constitutes a limitation when assessing impacts from the re-distribution of production factors, such as land, across the global economy.

Besides MRIO analysis, PE and CGE models are often used to examine economy-wide environmental impacts of livestock production and consumption. What distinguishes PE from CGE models is the PE models’ focus on specific sectors or supply chains, such as agri-food sectors in case of the Common Agricultural Policy Regionalized Impact model (CAPRI, (Britz and Witzke 2014)). PE models do not capture linkages with the rest of the economy. They typically assume completely elastic supply of intermediate inputs from non-covered sectors and take macro-economic variables such as income as given. In contrast, CGE models represent the entire economy and consider linkages among all sectors and economic agents, but are typically less detailed compared to specialized PE models. The data underlying CGE analysis are often structured as a so-called Social Accounting Matrix (SAM), which extends the conventional IO tables to include information on transactions across the global economy (Burfisher 2017). In both PE and CGE models, quantities and prices of products and resources adjust when markets clear, reflecting changes in production technologies and final demand, subject to resource constraints. This is beneficial to study adaptations in the EU livestock sector in response to CAP Post-2020 measures. For instance, Jansson and Säll (2018) use CAPRI to quantify the effect of a carbon tax policy on livestock production, while (Gocht et al. 2016) develop a spatially-explicit approach that combines CAPRI with the biogeochemistry CENURY model to look at effects from a 5% increase in pastureland area in the EU. Similarly, Kolasa-Więcek (2015) uses the CGE model LEITAP (Banse et al. 2008; Woltjer et al. 2014), now known as MAGNET, to assess potential environmental risks of Land Use Change (LUC) and GHG emissions associated with the EU’s livestock production. The CGE model DART-bio has been used to simulate a tax on meat consumption in the EU (Delzeit et al. 2018), or changes in dietary pattern towards less animal proteins (Calzadilla et al. 2014).

Independent of the model used, the level of detail in the underlying databases limits the study of supply- or demand-driven shocks to agri-food sectors. This can provoke bias, an issue widely discussed in MRIO analysis (Arto et al. 2014; Koning et al. 2015; Steen-Olsen et al. 2014), but also addressed by CGE analysists (Britz and van der Mensbrugghe 2016). For instance, the 21 agri-food sectors covered by the widely used and globally consistent GTAP database (Aguiar et al. 2019) which underlines many global CGE studies may be insufficient for comprehensive analyses of the LUC effects of economy-wide food-feed-fuel competition, as it features, for example, only one vegetable oil and protein cake sector. Here, the hybrid MRIO model called “Food and Agriculture Biomass Input-Output” (FABIO) (Bruckner et al. 2019a) can enrich the analysis. Drawing on production, trade and utilization data from the Food and Agriculture Organization (FAO). It covers 191 countries, 127 agricultural and food products, and 3 forestry commodities in physical units; providing a detailed representation of global intermediate and final consumption of bio-based products over the period 1986-2013. As such, it bears great potential to increase the resolution of the MRIO and CGE databases used to date.

In this regard, and in order to address the economy-wide impacts and related spillovers from an increased support to the EU extensive livestock sector, this study employs an integrated CGE-MRIO approach, in which we link the well-known GTAP-CGE model to the FABIO MRIO. This approach allows to take advantage of both methods. FABIO offers better resolution with regards to agricultural sectors than in the GTAP database. Additionally, this integration allows to overcome theoretical weaknesses of the MRIO method by employing CGE model, which is more suitable for policy analyses and long run assessments of changes in the global economy, such as with regard to climate change impacts (Walmsley et al. 2014; Carrico et al. 2020). Due to different technical challenges, e.g., data harmonization and balancing problems, a look at the recent literature shows that only few studies have adopted such a CGE-MRIO approach for global analyses of agri-food value chains, e.g. (Walmsley et al. 2014; Carrico et al. 2020) while no study focusing on the EU livestock sector can be found.

3 Materials and Methods

3.1 *Model setting and database preparation*

This study employs a recursive-dynamic version of the standard GTAP model (Hertel 1997), namely the GTAP Recursive Dynamic Extended Model (G-RDEM) (Britz and Roson 2018; Roson and Britz 2021), developed to assess long-run dynamics of economy-environment interactions. G-RDEM is available as a module in the modular and extendable platform for CGE modelling CGEBox (Britz and van der Mensbrugghe 2018). The GTAP-AEZ (Lee et al. 2005) and GTAP-E modules (Burniaux and Truong 2002) are also implemented in CGEBox to respectively represent conversion of land among productive uses as well as substitution between capital and energy in the production structure of sectors.

In G-RDEM (Britz and Roson 2018; Roson and Britz 2021), Total Factor Productivity (TFP) is endogenously determined during baseline generation, driven by exogenous GDP projections. Resulting TFP shifters are taken as exogenous for counterfactuals, whereas GDP becomes endogenous. Besides the usual capital accumulation process considered in recursive-dynamic CGE models, G-RDEM introduces five major features, namely:

1. An empirically estimated An Implicitly Directly Additive Demand System (AIDADS)[3] in replacement of the Constant Difference in Elasticity (CDE) demand system to better simulate income dynamics in demand (especially relevant for agri-food sectors), by means of exponential Engel curves (Ho et al. 2020);
2. Endogenous savings rates driven by income and demographic dynamics.
3. Differentiated productivity growth rates across the three main sectors of the economy, i.e., agriculture, manufacturing and service;
4. Debt accumulation from foreign savings, related to imbalances in the balance of trade;
5. Cost-shares that adjust over time according to income changes.

Moreover, an extended version of the GTAP-AEZ model (Lee et al. 2005) is employed, taken from Nong et al. (2020) and Escobar and Britz (2021), which considers the possibility to convert natural land cover at the Agro-Ecological Zone (AEZ) level to land in economic use. This version replaces the conventional nested Constant Elasticity of Transformation (CET) structure that maximizes total land rents while keeping total land stock fixed. It combines estimates of total natural land areas potentially converted into agricultural uses per region and AEZ based on (Eitelberg et al. 2015) with country-specific land supply elasticities, which are calibrated based on the FAO (2018) cropland projections and applied to a land buffer with respect to land rents. When land rents increase, new land is supplied to the upper nest of the extended land transformation structure (figure 1), while land transformation among productive uses is simulated with a 3-tier CET function. The updated land supply function in GTAP-AEZ is shown in figure 1.

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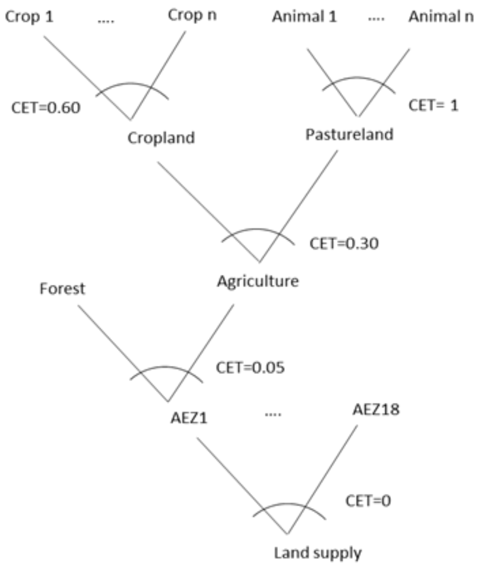
[3] The latest version draws on Britz (2021).

Figure 1. Extended nested land supply structure in GTAP-AEZ

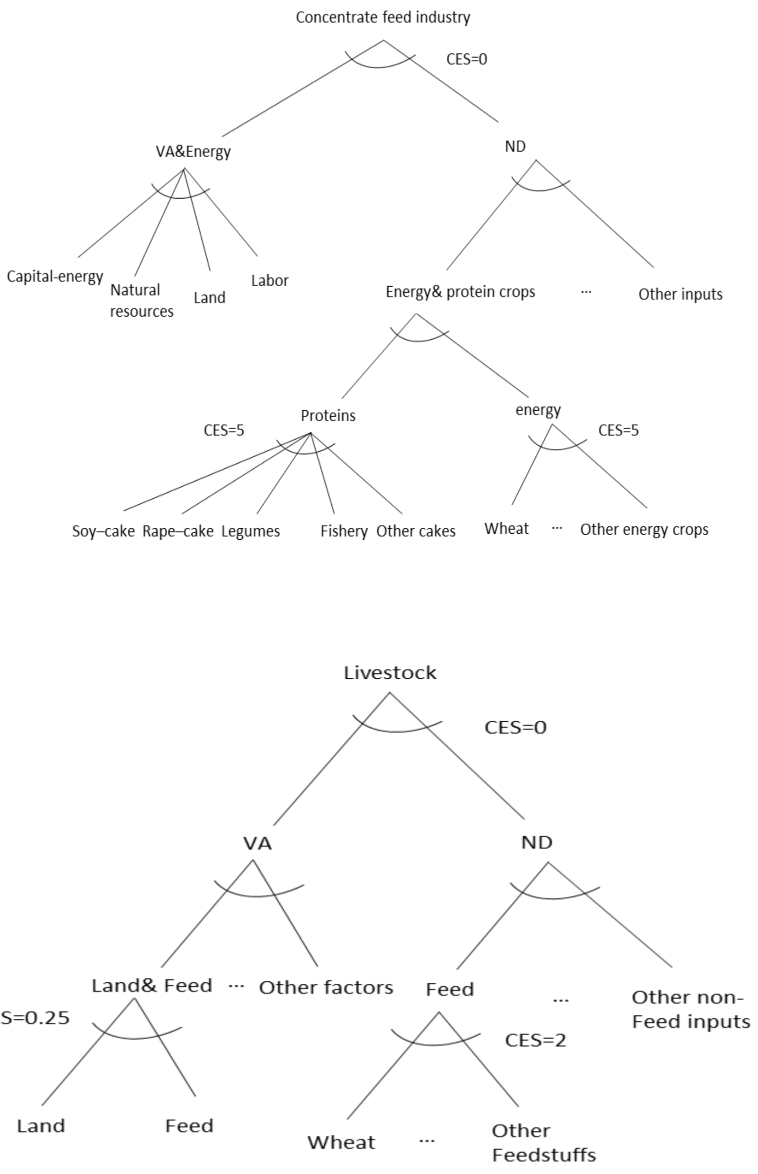


The production function of the concentrate feed industry is also extended by introducing by CES nests that differentiate between energy (sugar- and starch-based) and protein-rich crops (figure 2a). Considering high substitution possibilities among raw materials in the compound feed industry (Manceron et al. 2014), an elasticity of 5 is considered in the two nests. Additionally, substitution between pastureland and different feedstuffs (with a substitution elasticity of 0.25) is introduced in the production structure of livestock sectors (figure 2b) to adjust the intensive margin of livestock production as proposed by Golub et al. (2007). This means that an increase in land rents will translate increased intensification of livestock production by a higher use of feed concentrates and less pasture.

Figure 2. Extended production technologies in the compound feed industry (a) and livestock production (b)

(a)

(b)



3.2 *Database disaggregation*

This study departs from the GTAP version 10 database, with the base year 2014 (Aguiar et al. 2019), extended with auxiliary datasets, namely GTAP-AEZ (Lee et al. 2005) to include physical land at AEZ level and CO_2 emissions from carbon stock changes due to LUC; GTAP-E (Burniaux and Truong 2002)) to estimate CO_2 emissions related to fossil fuel use across sectors; and (Rose and Lee 2008) to quantify non-CO_2 emissions (CH_4, N_2O and F-Gases) from agricultural and industrial activities, differentiated by sector, country and source. The original GTAP 10 database is aggregated into 36 larger regions, while keeping the full sectoral resolution of 65 sectors. Most EU Member States are kept separate, in line with the objective of the study (Table A1 in appendix). The 65 sectors are extended to 75 to cover 31 agri-food sectors, relative to the original 21 sectors in GTAP 10. Specifically, production, consumption and bilateral trade information from FABIO (Bruckner et al. 2019a) is used to consistently split the GTAP sector Oilseeds, Vegetable oils, Vegetables and fruits, and Other food into additional sub-sectors (Table 1), by using the SAM split utility in CGEBox (Britz 2021). This is based on calculating split factors from FABIO, i.e., shares on output, bilateral trade, land use, final demand, and intermediate demand while the common 'proportionality assumption' (Walmsley et al. 2014) is applied to estimate intermediate and final demand for the new sub-sectors in case of missing information. This relates mainly to intermediate non-agri-food demand. The split of the sector Vegetable oils generates a non-diagonal SAM to represent crushing of specific oilseeds into cake and oil, allowing to distinguish between food and feed applications.

Table 1: Additional sectors disaggregated from the original GTAP 10 database (Aguiar et al. 2019) based on relative split factors estimated from FABIO (Bruckner et al. 2019a).

Original GTAP sectors	*New sub-sectors based on FABIO data*
Oilseeds	Olive; Soybean; Palm oil fruits; Rape and mustard seed
	Other oilseeds
Vegetable Oils	Olive oil production => olive oil
	Soybean crushing => Soybean oil, cake
	Palm oil production => palm oil
	Rapeseed crushing => Rape seed oil, cake
	Other oilseed crushing => Other cakes and oils
Vegetables and fruits	Legumes; vegetables, other vegetables, and fruits
Other food processing	Feed concentrate; Other food processing

3.3 *Simulation design*

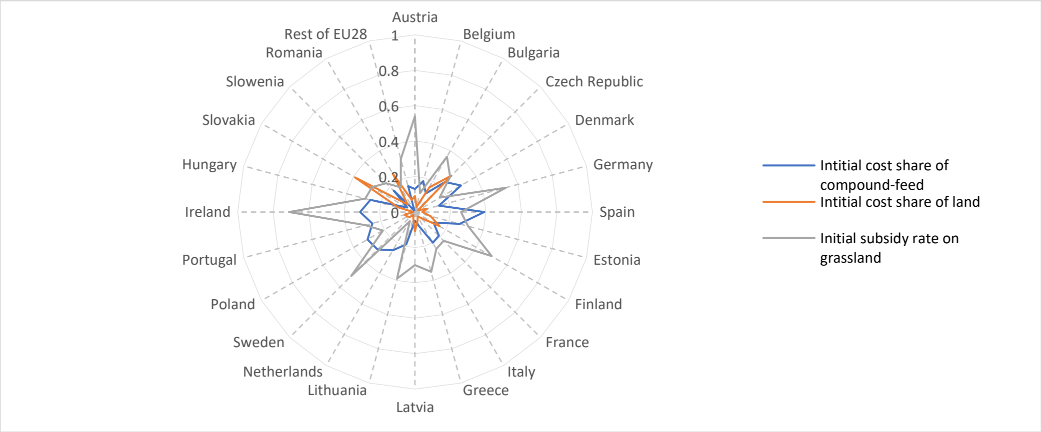
In recursive-dynamic CGE analysis, effects of an external shock on the economy are analyzed against a baseline, here capturing expected economic developments in the medium term. The baseline is constructed over the period 2014-2030 by using GTAP-RDEM. Based on the narrative of the Socio-Economic Pathway 2 (SSP2) (Riahi et al. 2017), which represents a continuation of past economic and demographic trends, projections of growth in GDP, as well as population by age group and education levels under moderate climate change adaptation and mitigation challenges are taken as given from other studies.

The counterfactual scenario captures the re-distribution of existing CAP subsidies from cropland to pastureland. This is modelled in a budget-neutral way, such that increased subsidies on pastureland are offset by lower ones to other crops, as proposed by (EC European Commission 2018; Hecht et al.

2016). Specifically, it is assumed that subsidies allocated to pastureland are at least two times higher than subsidies to cropland, but not exceeding a subsidy rate of 80%. To ensure budget neutrality, total subsidies to land in each EU country are held fixed at benchmark level. To do so, we exogenize the total subsidy costs for land in each EU country and introduce an endogenous correction variable to the updated subsidy rate according to the shock. This tax-recycling mechanism is also applied during the baseline generation and keeps CAP payments to land fixed in real terms. All other subsidy and tax rates besides land subsidies in EU Member States are kept unchanged.

Simulated impacts are expected to vary access EU Member States, due to differing biophysical conditions and dominating farming systems. Figure 3 highlight these differences based on a characterization of ruminant-livestock sector in the different EU countries at the benchmark in 2030 considering three main attributes, namely (1) the cost share of concentrate feed, (2) the cost share of land, and (3) the subsidy rate on pastureland that may significantly drive potential economic and environmental impacts from that “tax-recycling strategy”. The first two factors could indicate the intensification level of livestock production.

Figure 3. Characterization of the livestock sector in the EU28 countries based on GTAP10 database



As seen from figure 3, low subsidy rates (below 20%) are found in some countries, such as in Belgium (11%), Denmark (16%) and Netherlands (6%), while high support (more than 50%) is observed in Austria (54%), Germany (53%), Sweden (51%) and Ireland (71%). The cost share of concentrate feed is in general high in most of EU Member States, except in certain Eastern EU countries, such as Romania, Latvia and Slovakia, where it does not exceed 5%. These countries rely on a more extensive farming system, with also implies higher cost shares for land compared to Western-EU Member States. For example, land cost shares do not exceed 2%, in Netherlands, Denmark and Ireland. Initial pastureland subsidies will significantly drive the results. Where subsidies are already high, the maximal considered subsidization rate of 80% will prevent stronger increases and thus limit adjustment. In contrasts, farmers in countries where initial subsidy rates are low will have higher incentives to convert crop and other land to pastureland. Equally, the original intensification level plays an important part. As concentrate feed costs are expected to increase when crop land subsidies drop and thus crop production costs increase, a high initial cost share of concentrate feed will reduce incentives to expand ruminant production. This can limit the pastureland expansion in response to increased subsidies. Hence, higher expansion rates of grass-based cattle production are expected in countries with relatively low initial subsidies on pastureland, but also low concentrate feeding, e.g., Romania and Slovakia. Equally, the simulated “tax recycling strategy” promoting extensive cattle farming will result in higher pastureland expansion in countries where conversion to pastureland is more easily.

4 Results

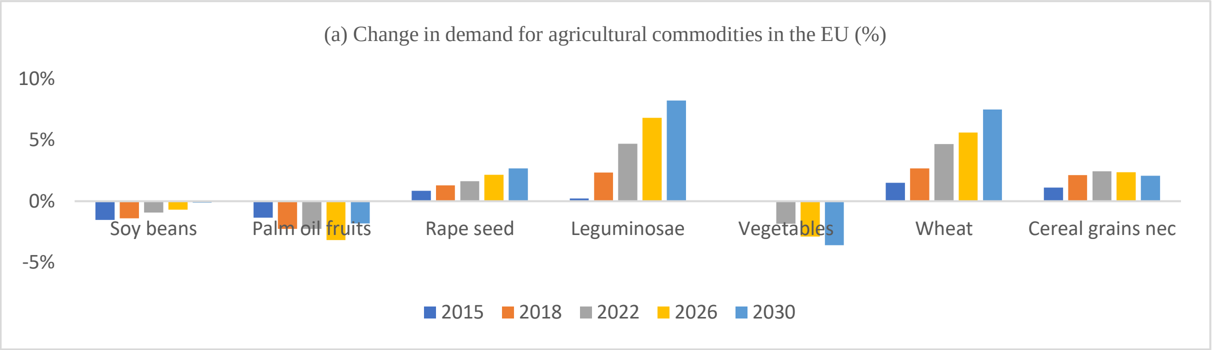
4.1 *Baseline results*

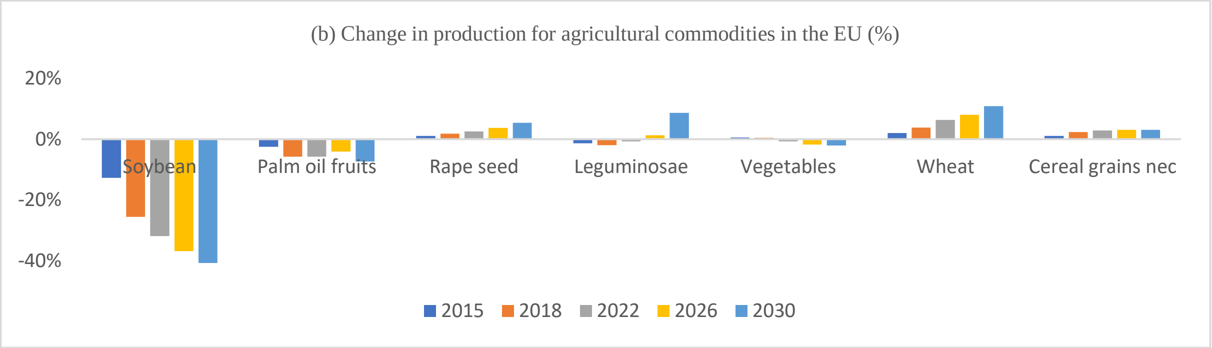
This section describes the main socioeconomic and environmental outcomes of the baseline over the period 2014-2030, based on the given projection of macro-economic variables under SSP2. The presentation focuses on crop and livestock production and consumption, land areas and prices. LUC results refer to the combination of all price-induced land substitution effects that take place on a global scale until 2030.

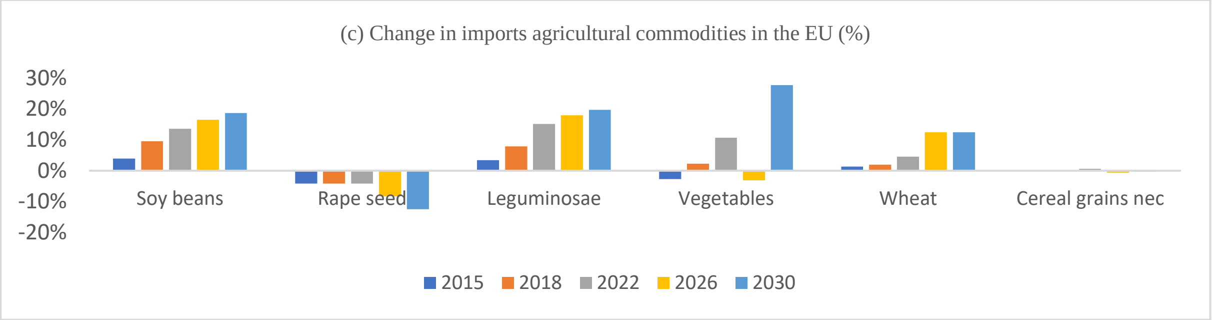
Driven by changes in GDP and population growth, the baseline shows a continuous growth in the EU demand for agricultural products until 2030 (Figure 4). For instance, demand for food and feed crops increase significantly, e.g., +7.51% for wheat, +2.67% for rapeseed, and +8.24% for legumes. An increase in the demand for oilseed crush is also projected, namely for rapeseed meal (+6.68%) and soybean meal (+13.93%). A further driver is the increased use of primary crops to produce biochemicals and biofuels. For instance, the input demand for vegetable oils used by the EU chemical industry is projected to rise considerably, e.g., for rapeseed oil by +23.53% and for soybean oil by +20%.

The projected expansion in the EU demand for agricultural products is accompanied with a significant increase in the EU supply of food and feed crops (Figure 4b), e.g., wheat production registers an increase of (+10.92%), rapeseed (+5.40%) and legumes (+8.67%). However, for certain other crops, increased demand is essentially met through higher imports (Figure 4c), e.g., total EU imports of soybean rise by 18.64%. This results in increasing production of agricultural commodities in exporting countries with abundant natural resources, such as Brazil and Southeast Asia. Thus, the EU continues to contribute to increasing global crop production (Figure 4d). Figure 5 shows changes in EU imports of agricultural commodities, namely oilseeds, vegetable oils and meals (Figure 5a) and cereals and other crops (Figure 5b) by main exporting countries. Brazil is expected to show a drastic increase in its exports of soybeans (+48.59%) and related products: oil (+12.90%) and meal (+39.88%). EU imports of cereals and other crops are also expected to increase in the medium term, namely wheat from North America (+36.11%) and sugar cane from sub-Saharan Africa (+79.37%).

Figure 4. Projected changes in production, demand, and imports of agricultural commodities relative to the year 2014 (%), in the Socio-Economic Pathway 2 (SSP2) scenario.


(a) Change in demand for agricultural commodities in the EU (%)


(b) Change in production for agricultural commodities in the EU (%)


(c) Change in imports agricultural commodities in the EU (%)

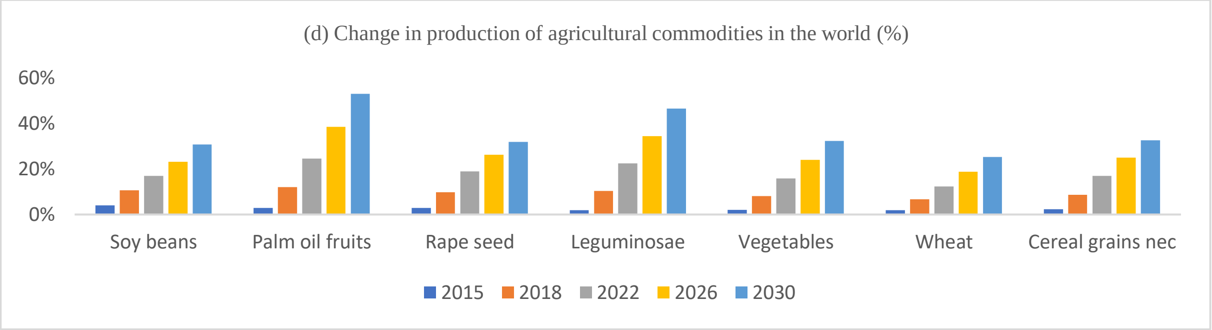
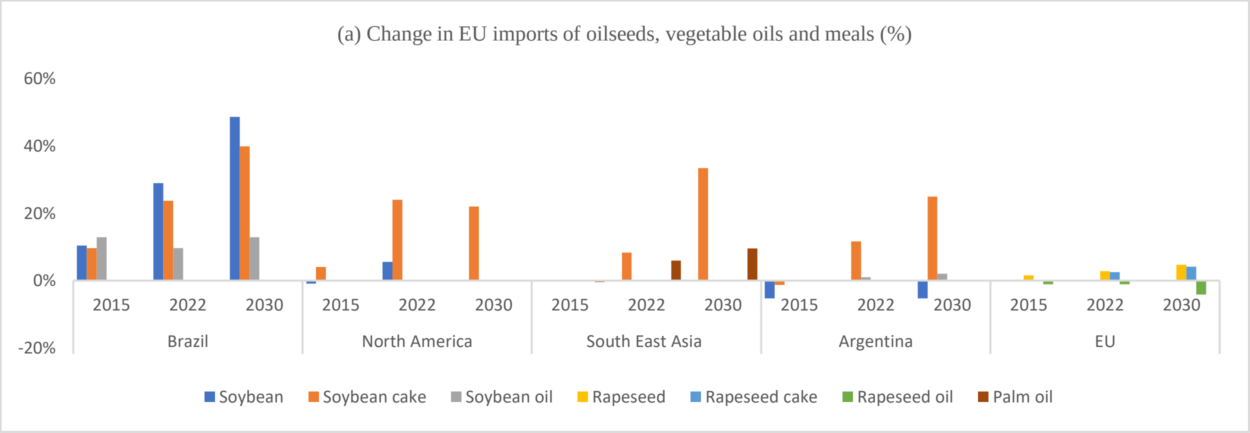
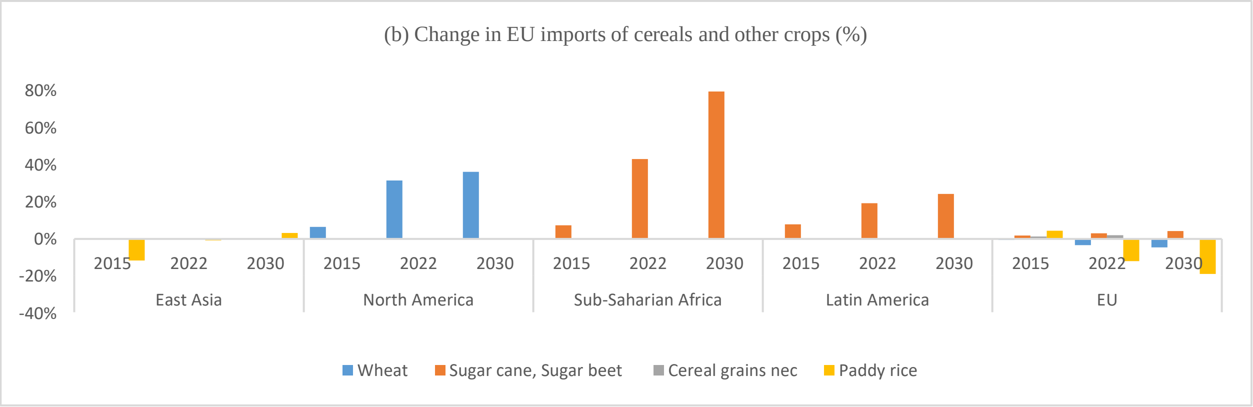

(d) Change in production of agricultural commodities in the world (%)

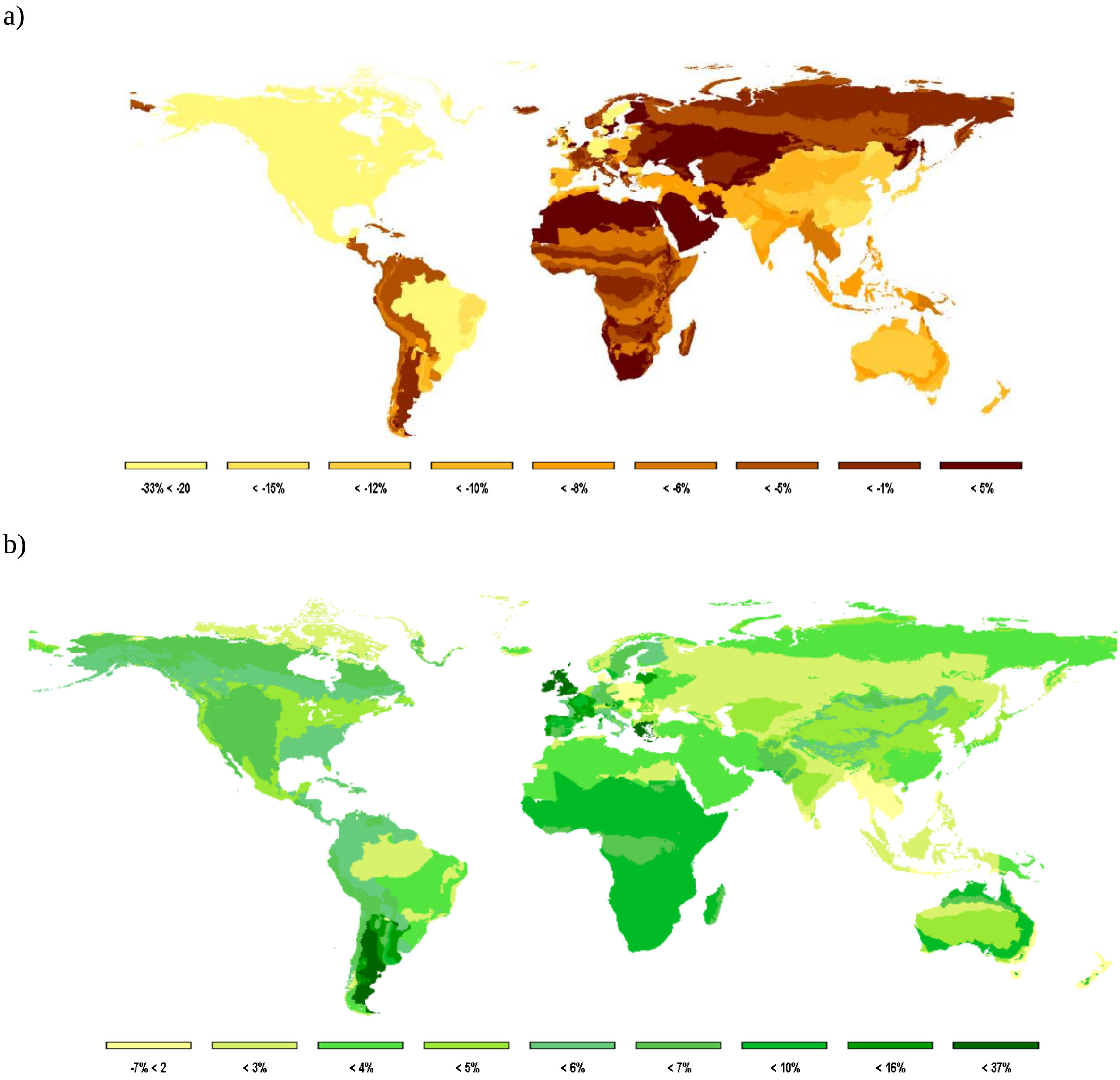
Figure 5. Change imports of agricultural commodities into the European Union (EU) by main exporting country relative to the year 2014 (%), in the Socio-Economic Pathway 2 (SSP2) scenario.


(a) Change in EU imports of oilseeds, vegetable oils and meals (%)


(b) Change in EU imports of cereals and other crops (%)

The projected increase in the EU's demand for primary crops, from both intra and extra-EU markets, is associated with sizeable global LUC effects. Figure 5 shows changes in the pastureland and cropland areas up to 2030, relative to 2014. Due to limited land resources, pastureland areas decrease significantly in most EU countries, for instance by -20.67% in Germany and AEZ-9) and by -11.45% in France and AEZ-11. Pastureland however expands in several regions (by up to +5%), mostly outside the EU, such as in Middle East and North Africa (MENA), parts of North America, Central Asia, Southern Africa, South-Eastern Asia (SEA) and Western Pacific as well as in the North-Eastern and central regions of Brazil. Cropland increases in most of EU countries, such as in Ireland (+28.89% in AEZ12), France (+10.28% in AEZ11) and Italy (+5.22% in AEZ11) as well as in other regions, such as in North America (+8.31%), Southern Asia (+12.29%) and South America (+27.57%).

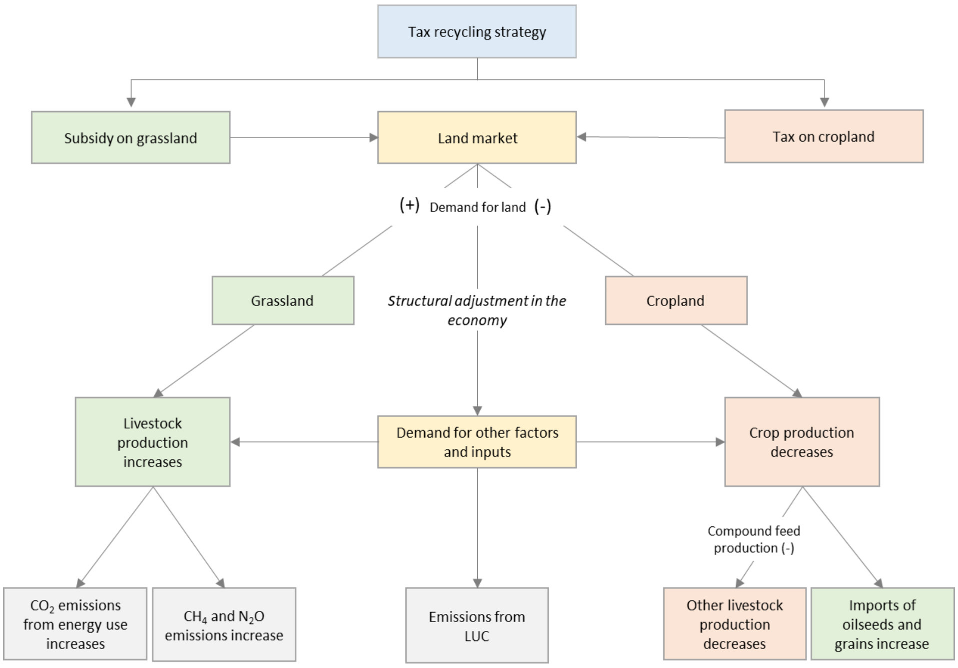
Figure 5. (a) Pastureland cover change in 2030 (%) relative to the year 2014. (b) Cropland cover change in 2030 (%) relative to the year 2014.



4.2 *Market-mediated impacts of the tax-recycling strategy*

The expected market-mediated effects of the simulated “tax recycling strategy” are summarized in figure 6, in order to facilitate the understanding of the results below.

Figure 6. Flow chart of economic and environmental effects of increases land-based payments to cattle sector in the European Union (EU) at the expense of cropping activities.



Note: Green boxes indicate an increase. Red boxes indicate a decrease. Grey boxes indicate impacts on GHG emissions. Yellow boxes indicate impacts on land market and subsequent effects on the economy

Higher subsidies and thus reduced pastureland prices translate into reduced production costs for ruminant livestock production. This generates an increased demand for land in the EU livestock sector. It promotes substitution of feed concentrates and supplements, and favors ruminant production over other livestock systems. The "tax recycling strategy" has the opposite effect on crop production: crop land use gets more expensive such that arable land use and crop production decrease in the EU. These adjustments entail changes in prices of agricultural commodities, i.e., decreasing prices of livestock products and increasing prices of crops. This has implications in other sectors that use primary crops as intermediate inputs, mainly non-ruminant livestock (i.e., pig and poultry) and concentrate feed production, where production costs increase. Dropping ruminant meat prices and increases for other agricultural product led to adjustment in final demand. Moreover, the adjustment in production requires a reallocation of production factors and intermediate inputs across economic sectors, driven by changes in land rents and subject to the degree of substitution between land and other production factors (inputs). Increases in pastureland subsidies decrease the feed use of crops and let to pastureland expansion. Moreover, decreased production costs in cattle production may result in additional adjustments, for instance, by increases in the demand for other production factors and intermediate inputs that are not associated with the use of land, e.g., labour. It must be taken into account that the extended GTAP-AEZ module (Figure 1) is expected to mitigate this effect, as new land can be brought into productive uses. All these market responses will ultimately have environmental implications in terms of LUC and GHG emissions, as discussed below. In the following, results from the tax-recycling strategy supporting pastureland-based cattle production are presented as percentage changes relative to the baseline scenario in 2030. They reflect the net effect of all adjustments to the simultaneous increase in land-based payment to the cattle sector and the decrease in land-based support to crop production.

Changes in subsidy rates across EU Member States up to the year 2030 are shown in table A2 in the appendix. These tax rate adjustments are not uniform across countries. They reflect the original budget allocation between pastureland and cropland: the higher the share of cropland subsidies in total land subsidies, the smaller is the resulting drop. Moreover, as any increase in pastureland subsidies beyond a subsidy rate of 80% is not allowed in the simulation (see section 3.3), countries with a high subsidy rate for pastureland in the baseline show little change in the tax rates, such as in Ireland (+6.96%). Land-based payments to ruminant production increase by almost threefold in countries where initial payments are rather low, such as in Belgium (+213.06%), Denmark (+196.65%), and Italy (+199.52%). Figure 7 shows simulated output and price effects on the EU ruminant livestock sectors.

Figure 7. Changes in production of ruminants (a) and associated prices (b) in domestic markets across the European Union (EU) in 2023 and 2030 [% change relative to the baseline]

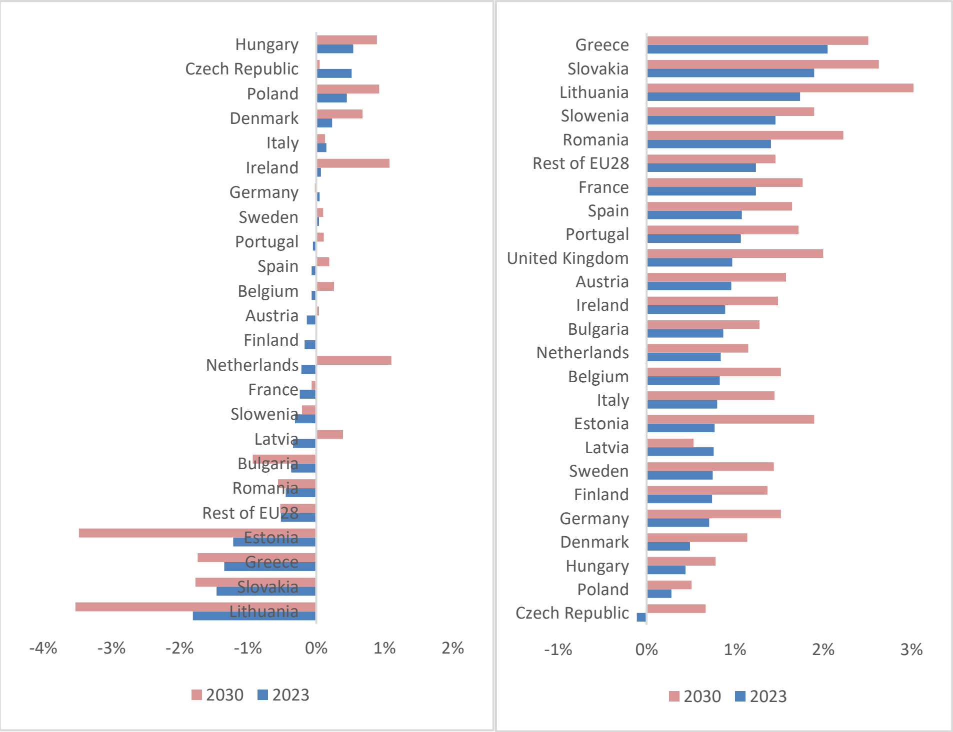
(a) (b)

As seen, market responses are quite diverse across EU countries. Their size clearly depends on the magnitude of the shock, i.e., greater subsidy changes provoke larger market effects. In countries where payments to pastureland are already high in the baseline, such as in Ireland, not much change in subsidy rate results (+6.96%) with a negligible effect on cattle production (+0.91% in 2030). In countries with rather low initial payments, significant substitution of pastureland for feed concentrates takes place, as the extensive margin effect prevails, and farmers benefit from increasing pastureland areas. For instance, in Romania, subsidy rates increase by +189.06% and let cattle output in 2030 increase by +7.44%. However, in some other countries, cattle production remains stagnant despite larger increases in pastureland subsidies. This is the case in countries where cattle production is largely based on concentrate feeding. Netherlands provides an example, with cattle production increasing by only 0.57% in 2030 relative to the baseline, despite a subsidy increase of 179.57%. Here, cost increases for concentrates due to higher crop prices offset cost savings from reduced pastureland prices.

In fact, reducing cropland-based support to boost extensive cattle production in the EU increases crop and feed concentrate prices (See table A3 in the appendix). For instance, the price of rapeseed meal which is mainly used in animal diets increase in Netherlands, Hungary, and Belgium by around 2%. The increase in crop prices, combined with an overall increase in concentrate feed demand in the EU cattle sector, contributes to increasing concentrate feed prices. For instance, concentrate prices increase in major EU ruminant producers, by 1.57% in France, 1.53% in Germany and 1.41% in Spain. This results in a relatively small expansion of cattle sector, i.e., production increases by 0.79%, 1.68% and 1.19%, respectively, in France, Germany and Spain. As expected, the pastureland subsidy is detrimental for the EU's supply of non-ruminant livestock (Figure 8), both due to lower prices for ruminant meat and higher concentrate feed cost. Hence, these sectors, encompassing pig and poultry, shrink in many EU countries, mainly in Lithuania (-3.53%) and Estonia (-3.48%), where a significant redistribution of production inputs and factors from non-ruminant to ruminant livestock sectors is observed. In other countries, non-ruminant livestock sectors even slightly expand, such as in Hungary, Poland, Ireland and Netherlands by around 1% in 2030 compared to the baseline.

As explained above, differences in livestock management systems and initial subsidies drive the varying impacts across EU countries from the land subsidy redistribution. The extent to which new land can be taken into production is equally important. The less elastic the land supply, the greater the changes in land rents and subsequent substitution effects between land use categories (See table A4 in the appendix). Land buffer data are available at national level, only, such that the strength of land expansion is not differentiated at the sub-national level. In countries where some additional land is assumed to be still available, such as in Germany, price-mediated effects from the subsidy changes recycling strategy are relatively smaller. Another example of this provides the Czech Republic, where the increased support to pastureland triggers a significant increase of cattle production (+19.91%) while cropping and other livestock activities are barely affected. However, in countries where data suggest that agricultural land resources are exhausted, the changes in land subsidy rate can provoke more significant price effects. For instance, in Greece, increases in wheat (+2.02%) and other cereal prices (+1.54%) contribute to a price increase of 2.51% in 2030 of other non-ruminant livestock products. Furthermore, results also depend on the relative shares of cropland and pastureland in total agricultural land area in the database. For instance, in Spain, where the share of cropland in total agricultural area is quite large with 73 % at the benchmark, financing an increase of pastureland subsidies does not require larger decreases in crop land subsidies. Accordingly, only minor changes in crop production are observed, for instance, wheat production adjusts only by -0.06%. The opposite is found in cases the share of cropland is originally low and where land is scarce, such that sizeable price effects and impacts on in crop production can result. This is however not in observed in Ireland despite a low crop land share of 25%, due to a muted increase in payments to pastureland by only +6.96%.

Figure 8. Changes in production of non-ruminants (a) and associated prices (b) in domestic markets across the European Union (EU) in 2023 and 2030 [% change relative to the baseline]



Overall, the shift in land subsidies generates a moderate decrease in production of traditional crops in the EU, such as rapeseed and wheat, partly also due to increasing market prices (See table A3 in the appendix). At the same time, imports of cereals, oilseeds, vegetable oils and cakes increase to compensate for lower domestic production (Table 2).

Table 2. Changes in total EU imports of agricultural products by origin, relative to the baseline in 2030; import values in (US$ billion).

	Cereals		*Oilseeds*		*Vegetable oils and cakes*		*total imports*		
	Baseline value	*absolute change*	*Baseline value*	*Absolute change*	*Baseline value*	*Absolute change*	*Baseline value*	*Absolute change*	*% change*
EU	11.26	0.24	5.44	0.12	16.65	0.36	33.35	0.72	2.16%
UK	0.46	0.01	0.21	0.01	0.6	0.01	1.27	0.03	2.36%
North America	1.71	0.03	1.98	0.05	0.85	0.01	4.54	0.09	1.98%
Brazil	0.11	0.00	2.59	0.07	3.6	0.10	6.3	0.17	2.70%
Argentina	0.04	0.00	0.18	0.02	2.9	0.03	3.12	0.05	1.60%
East Asia	0.03	0.00	0.16	0.01	0.15	0.00	0.34	0.01	2.94%
Southeast Asia	0	0.00	0	0.00	4.62	0.03	4.62	0.03	0.65%
South Asia	0.01	0.00	0.36	0.00	0.78	-0.01	1.15	-0.01	-0.87%
Latin America	0.2	0.00	0.5	-0.01	0.94	0.01	1.64	0.00	0.00%
Australia, New Zealand	0.03	0.00	0.69	0.00	0.22	0.01	0.94	0.01	1.06%
SSA	0.12	0.00	0.19	0.00	0.17	0.00	0.48	0.00	0.00%
MENA	0.08	0.01	0.06	0.00	0.19	0.01	0.33	0.02	6.06%
ROW	1.68	0.04	0.53	0.01	1.39	0.04	3.6	0.09	2.50%

As seen in table 2, the EU is expected to increase its cereal imports. Larger changes in relative terms are often observed in quite small import flows, such as for the MENA region (+0.01 US$ billion or +12.50%). Similarly, increases of oilseed imports from different sources are registered, e.g., from Argentina (+0.03 US$ billion or +11.11%) and East Asia (+0.01 US$ billion +6.25%) despite a slight decrease (-0.01 US$ billion or -2%) from Latin America. Similarly, imports of vegetable oils and cakes into the EU market rise, for example, by 0.01 US$ billion or 4.55% from Oceania and by 0.10 US$ billion or 2.78% from Brazil. Intra-EU trade is expected to rise as well, for cereals, oilseeds, vegetable oils and cakes by 0.24 US$ billion (+2.13%), 0.12 US$ billion (+2.21%) and 0.36 US$ billion (+2.16%), respectively. Countries where the subsidy shift has negligible impact on crop prices are expected to increase crop exports to other EU countries, such as, for instance, for the Czech Republic and wheat with around 6%. Similarly, in Ireland, where the policy results in a minor increase in payments to pastureland, oilseed and cereal exports to other EU Member States rise by 2.15+%. The subsidy changes make imported feedstuffs from third countries relatively cheaper than domestically produced ones in the EU, which results in an increased EU import of such feedstuffs. For instance, the UK increases its rapeseed cake exports to the EU the by 3.44%. Results also show larger soybean cake imports, which represents a major rich-protein feedstuff used in the EU feed industry, specifically from Brazil and North America, by 2.05% and 2.18 %, respectively.

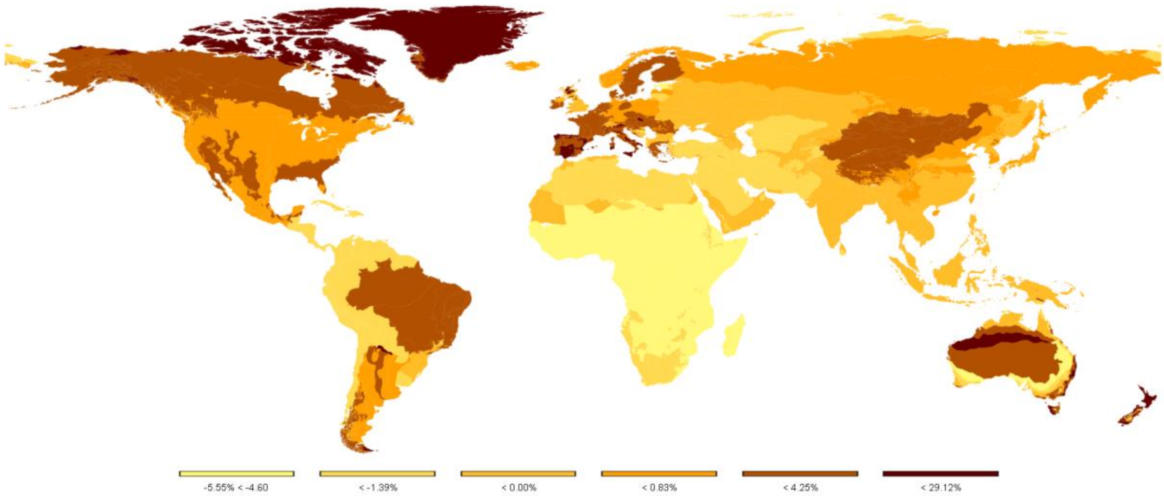
4.3 *Global LUC and GHG emissions from the tax-recycling strategy*

The aforementioned changes in agricultural production and trade generate considerable LUC both inside and outside the EU (figure 9). As expected, pastureland expands significantly in almost all EU Member States (figure 9a). This expansion is greater in countries where land resources are readily available, such as in Spain, France, Hungary, and Slovakia with increases of up to +6.81%. The reported changes refer to the maximal changes found in one of the AEZ. Lower land availability dampens the effect with up to +2.25% in other EU countries, such as Germany, Poland, Czech Republic, Denmark, Romania, Latvia and Italy. The subsidy shift implies lower support to crop production and let total cropland area decrease across the EU, by up to -7.20% in Greece and Estonia (figure 9b) and up to -1.64% in Spain, France, and Slovakia. However, cropland acreage also increases in some other countries, such as Ireland (+6.29%) where the subsidy increase for pastureland land is limited, and by up to +2.81% in Poland, Czech Republic, and Hungary. The increased EU demand for imported crops, essentially rich-protein crops from third countries (table 2) leads to an expansion of cropland area in major grain producing and exporting countries (up to +6.29%) such as in North America, Brazil, and by up to +11.61% in Argentina. Cropland is also projected to increase to a lower extent (up to +2.81%) in other countries and regions outside the EU, such as North America, East Asia, and by up to +0.53% in South-East Asia. With regard to forest cover, results show that the higher pastureland and lower crop land subsidies might increase managed forest lands. EU. For instance, forestland area increases up to +5.79% in Netherlands and Hungary, up to +2.61% in Ireland, Slovakia, and Czech Republic, and by around +0.71% in other countries such as Spain, Germany, France, Poland, and Romania. This also found outside the EU, such as in Brazil, Argentina, and North America (up to +2.61%). Nevertheless, managed forests decrease (up to -5.88%) in Sub-Saharan countries and to a lower extent (-0.97%) in parts of Latin America, South Asia, and MENA region. The LUC inside and outside the EU generate a slight average global decrease of pastureland (-0.18% or 800 thousand ha), cropland (-0.93% or 13559 thousand ha) and managed forests (-0.88% or 431 thousand ha). Accordingly, unmanaged forests register a relevant increase of around (+0.51% or 15728 thousand ha) relative to the baseline in 2030. This essentially occurs in Sub-Saharan countries, where unmanaged forests expand by +4.65% or 16322 thousand ha while it decreases in other regions and countries, such as in North America (-0.59% or 2664 thousand ha), East Asia (-

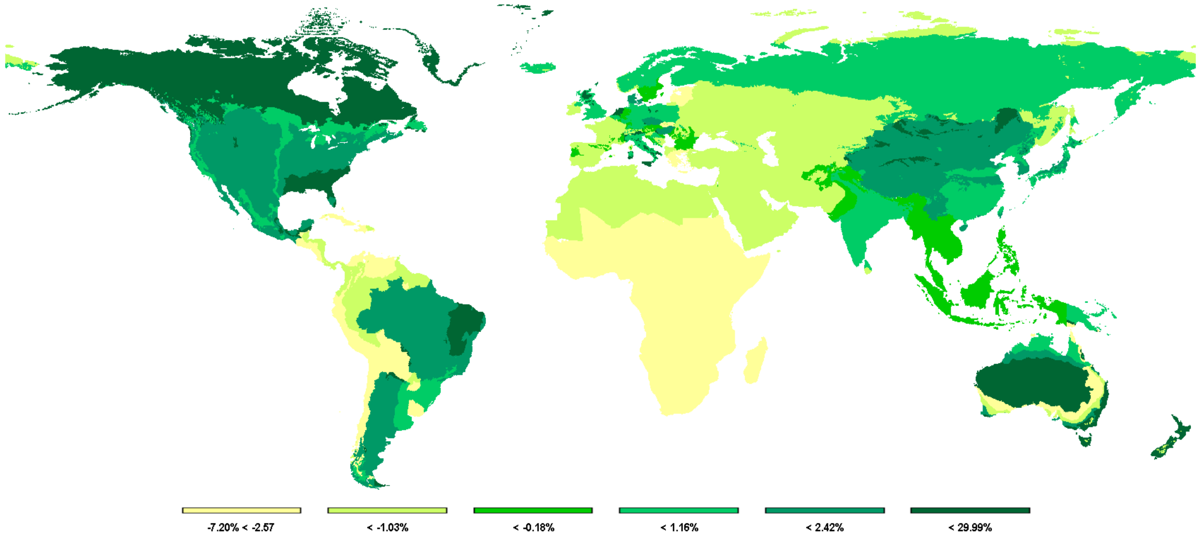
0.58% or 2376 thousand ha), Brazil (-0.94% or 1901 thousand ha) and Argentina (-1.17% or 238 thousand ha). In the EU, where the subsidy shifts generate a significant increase in pastureland area, a loss of unmanaged forests is registered in certain countries, such as in Germany (-0.43% or 71 thousand ha) and Italy (-1.74% or 221 thousand ha). However, other EU countries register a restoration of their natural forests, such as in France (+0.81% or 185 thousand ha), Greece (+3.46% or 114 thousand ha) and Slovakia (+0.52% or 14 thousand ha).

Figure 9. Changes (%) in land areas a) pastureland. b) cropland. c) managed forest. d) unmanaged forest in the year 2030 relative to 2014.

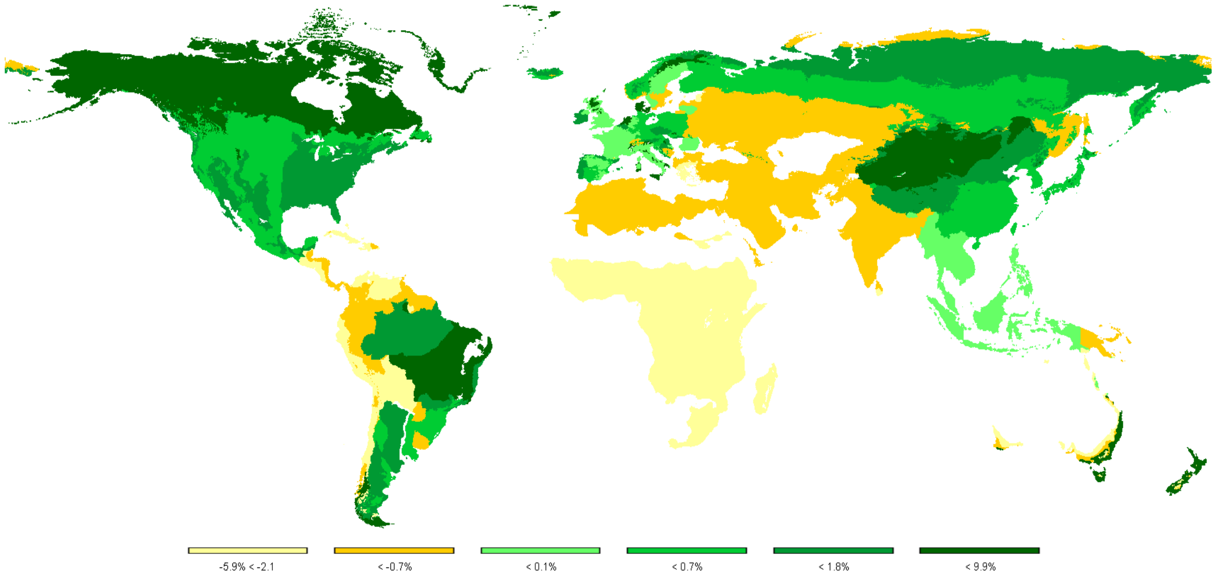
(a)



(b)



(c)



(d)

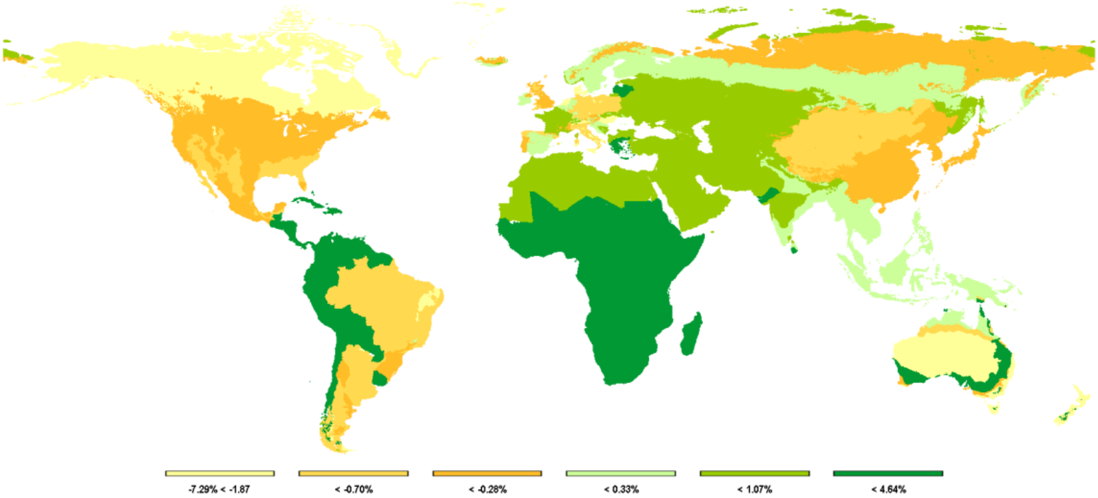


Table 3. Absolute changes in CO_2, non-CO_2 emissions and annualized LUC emissions in 2022 and 2030 relative to the baseline (million tonnes of CO_2-eq); and absolute and relative changes in total GHG emissions.

	all activities				LUC		Net GHG effect	
	2022	2030	2022	2030	2022	2030	2022	2030
Austria	0.22	0.68	0.82%	0.30%	0.36	0.53	0.22	1.21
Belgium	0.27	0.67	0.53%	0.25%	-0.29	0.48	0.27	1.15
Bulgaria	-0.09	-0.54	-0.58%	-0.13%	-0.44	-0.37	-0.09	-0.91
Czech Republic	0.35	-0.05	-0.03%	0.29%	1.35	1.13	0.35	1.08
Denmark	0.11	0.33	0.46%	0.19%	1.70	1.83	0.11	2.16
Germany	1.63	4.36	0.51%	0.22%	2.94	0.03	1.63	4.39
Spain	0.81	2.35	0.65%	0.27%	-1.85	-1.49	0.81	0.86
Estonia	-0.07	-0.22	-0.76%	-0.30%	-0.32	-1.28	-0.07	-1.50
Finland	0.16	0.46	0.46%	0.20%	0.60	0.49	0.16	0.95
France	0.46	1.83	0.45%	0.13%	-7.25	-7.55	0.46	-5.72
Italy	0.66	3.09	0.84%	0.21%	3.49	7.68	0.66	10.77
Greece	-2.97	-6.8	-4.13%	-2.06%	-11.51	-8.55	-2.97	-15.35
Latvia	-0.1	-0.14	-0.76%	-0.61%	-2.26	-2.40	-0.10	-2.54
Lithuania	-0.27	-0.62	-2.33%	-1.17%	-3.81	-5.57	-0.27	-6.19
Netherlands	0.28	2.23	1.17%	0.17%	0.85	0.87	0.28	3.10
Sweden	0.13	0.41	0.61%	0.24%	1.70	0.78	0.13	1.19
Poland	0.61	1.3	0.25%	0.15%	2.26	4.04	0.61	5.34
Portugal	0.23	0.66	0.71%	0.30%	0.09	0.13	0.23	0.79

Ireland	0.03	0.25	0.32%	0.05%	-0.07	-0.02	0.03	0.23
Hungary	0.02	0.02	0.03%	0.03%	0.63	1.07	0.02	1.09
Slovakia	0.02	0.02	0.06%	0.05%	-0.19	-0.34	0.02	-0.32
Slowenia	0	0.06	0.31%	0.03%	0.03	0.06	0.00	0.12
Romania	0.41	0.89	0.63%	0.39%	-0.04	-0.05	0.41	0.84
Rest of EU	-0.12	-0.29	-0.53%	-0.24%	-0.56	0.04	-0.12	-0.25
World	53.88	-22.58	-0.03%	0.10%	39.92	-516.28	93.80	-538.86

The land subsidy re-allocation in the EU generates significant changes in GHG emissions (as CO_2-eq,) resulting from both global LUC and economy-wide adjustments (table 3). The here calculated net GHG emission effect from this strategy comprises therefore, in addition to CO_2 emissions from energy use, other non-CO_2 emissions which include CH_4 emissions from enteric fermentation and manure management, as well as N_2O emissions from synthetic nitrogen fertilizer application. The calculation of changes in GHG emissions also considers changes in carbon stocks due to LUC, which are estimated by the model in each year and then amortized linearly over 20 years, in line with the time horizon considered in the AEZ-EF model (Plevin et al. 2014). This allows to consider the induced LUC emissions in the calculation of the net GHG effect and to compare them with changes in annual emissions from economic activities.

Compared to the baseline in 2030, the simulated subsidy shifts generate a slight increase in net GHG emissions in the EU in total (+2.49 Mt CO_2-eq in 2030). This is mainly due to the increase in emissions from CO2 and non-Co2 emissions (+10.95 Mt CO_2-eq in 2030). They offset emissions reduction from LUC and subsequent increase in biomass and soil carbon sequestration (-8.45 Mt CO_2-eq in 2030). However, impacts among EU Member States are highly heterogeneous (Table 3). We distinguish countries that are expected to register a net reduction in their GHG emissions from the implementation of this strategy, such as in Greece, France, and Lithuania, by -15.35 Mt CO_2-eq, -5.20 Mt CO_2-eq and -6.19 Mt CO_2-eq relative to the baseline in 2030, respectively. These emission reductions are essentially resulting from the increased carbon sequestration due to the expansion of pastureland and a simultaneous preservation of unmanaged forests. In these cases, they offset higher methane emissions from expanded ruminant production as the main driver of CO_2 and non-CO_2 emission. In fact, in those countries, the strategy results in an increase in pastureland area that is basically converted from already cultivated land, i.e., cropland while no new land, i.e., unmanaged forest and other natural land which represent a major carbon store are brought into cultivation. This allows to release less carbon to the atmosphere. For example, in France, where the promotion of pastureland comes at the expense of cropland (up to -1.64% in 2030) while unmanaged forest increases (+0.81% or 185 thousand ha), emissions from LUC are expected to decrease by 7.55 Mt CO_2-eq in 2030. Similarly, in Greece, the decrease in land-based support to cropping activities and the significant induced decrease in cropland area (up to -7.20%) at the profit of pastureland area results in an overall decrease in emissions from LUC (-8.55 Mt CO_2-eq). Results also suggest that net emissions in other EU countries are expected to increase, mainly in Italy (+10.77 Mt CO_2-eq), Poland (+5.34 Mt CO_2-eq), Germany (+4.39 Mt CO_2-eq), Netherlands (+3.10 Mt CO_2-eq) and Denmark (+2.16 Mt CO_2-eq). For the majority of these countries, this effect results from a simultaneous increase in both emissions from LUC and economic activities. Nevertheless, in countries where land resources are readily available and crop production is barely affected, emissions from LUC are expected to contribute the most to that increase in net GHG emissions as new land is brought into cultivation. For example, in Hungary, the expansion of pastureland area comes essentially at the expense of unmanaged forest (-68 thousand ha), leading to an increase of emissions from LUC of +1.07 Mt CO_2-eq. Spain and Ireland are the only two member states where the increase in emissions from economic activities totally offset emissions reduction from LUC, leading to a net increase in overall GHGs by 0.23 Mt CO_2-eq and +0.86 Mt CO_2-eq, in Ireland and Spain, respectively. While this can be explained by the overall small effect of the subsidy shifts for the case of Ireland, in Spain, the emissions reduction potential from LUC is expected to be relatively small comparing to other countries, such as France. In fact, the expansion of pastureland in Spain comes basically at the expense of cropland and unmanaged forest while managed forests with lower carbon stock increase slightly. In addition, Spain sees a higher increase relative to LUC effects from changes in CO2 and non-CO2 emissions. For instance, CH_4 from cattle production increase by 0.18 Mt CO_2-eq, which represents the second highest increase among all EU Member States, after the Czech Republic.

Although the simulated subsidy shifts in the EU result in a slight increase in its total GHG emissions (+2.49 Mt CO_2-eq in 2030), it will generate a significant decrease in GHG emissions globally (-538.86 MT CO2-eq in 2030). In fact, ILUC outside the EU-border led to a considerable decrease in carbon emission by expansion of pastureland and unmanaged natural forest in many regions, essentially in Sub-Saharan Africa (-557 Mt CO_2-eq in 2030). This allows to offset potential increase in LUC emissions in other countries, essentially in main EU agricultural trade partners such as Brazil and North America where cropland expand to meet the EU demand in protein-rich crops (Figure 9b). For instance, emissions from LUC increase by 102.52 Mt CO_2-eq in Brazil and by 129.17 Mt CO_2-eq in North America.

5 Discussion

The analysis highlights the importance of considering global and economy-wide effects when assessing the land use and GHG implications of policy support to extensive livestock production in the EU. Previous studies on this topic mostly employ supply chain or farm models, which allow for more detailed analysis of local and sectoral effects, but cannot consider price induced changes outside the EU. Thus, complementary analyses are needed to understand the global spillover effects of EU-wide interventions, since these are mediated by international trade, such as price-induced LUC. This study therefore employs a recursive-dynamic CGE model with environmental modules for land use and GHG emission accounting to estimate the medium-term sustainability of a shifts in land subsidies which promote more extensive cattle production in the EU. Such intervention is widely discussed in the framework of the CAP since it is expected to improve environmental ecosystem services, for instance, by (1) reducing pastureland degradation, (2) increasing carbon sequestration, and (3) decreasing GHG emissions.

5.1 *Mitigation potential of the "tax recycling strategy" at the EU level*

The experiment consists of simulating a redistribution of CAP land-based payments through an EU-wide "tax recycling strategy" that subsidizes ruminant grazing at the expense of other cropping activities in the mid-term (2014-2030). Results indeed show that an increase of returns to land in the cattle sector motivate farmers to shift more land into grazing, by converting cropland to pastureland. This strategy affects the EU countries however quite differently, depending on the one hand on the production structure of their cattle sector (more or less intensive); on the other hand, on the availability of additional land extension to be brought into cultivation. Greater pastureland expansion is observed across EU countries, where land resources are less constrained and where the strategy leads to significant land allocation from cropland to pastureland, such as in France. The subsidy shifts show limited impacts in countries with lower land buffers, such as in Greece, but also in Member States that rely on concentrate feeding to a large extent, such as the Netherlands. Our simulated expansion in pastureland area by 2.10% or around 1 Mha compare quite well to those from Gocht et al. (2016), who employ the PE model CAPRI integrated with the biochemistry CENTURY model to simulate a strategy that encourages EU farmers to increase pastureland area by 5% or around 2.9 Mha, through flexible payments. It is also important to mention that the original area of the EU pastureland in the baseline scenario in Gocht at al., (2016) is 58.5 Mha while it is around 46.7 Mha in our study. This difference is mainly explained by the non-inclusion of the UK, as former EU Member State with important grassland area of around 10 Mha. Gocht at al. (2016) find that a 5% increase in grassland area generates an emission reduction from carbon sequestration of 5.96 Mt CO_2-eq, which is partially offset by an increase of 1.75 Mt CO_2-eq from CH_4 and N_2O emissions. Results in terms of emission reduction from carbon sequestration are relatively comparable with our findings (-8.45 Mt CO_2-eq), taking into account that the two studies start from different modelling approaches. In addition, this higher carbon sequestration in the presented study could be also attributed to the scenario design that enforces a simultaneous decrease in cropland subsidies, which is not the case in Gocht at al. (2016). Hence, the "tax recycling strategy" implies that more cropland, with lower carbon stocks compared to natural forests, is converted to pastureland. With regard to emission increase from economy adjustments, which is here estimated at 10.95 Mt CO_2-eq, a clear difference occurs. In fact, Gocht et al. (2016) consider GHG emissions from agriculture while a net GHG emission effect is here calculated based on CO_2 and non-CO_2 from all economic sectors. A CGE-based study as ours may provide therefore a more accurate calculation in terms of net GHG effect from a policy promoting grassland in the EU. However, Gocht et al. (2016) provide more spatial details by simulating agricultural production at the Nuts-2 level, which reduces potential aggregation bias, and depict subsidies in far more detail.

5.2 *Carbon leakage and emissions spillover*

The simulated increase in pastureland subsidy is detrimental for the EU's supply of pig and poultry and other livestock, due to increasing crop prices, which entail higher concentrate feed cost. As a net effect, EU imports of feedstuffs increase. Traditional feed crops and crushes are still largely met with intra-EU imports, specifically from those countries that are barely affected by the strategy and where pastureland support is already notable, e.g., Ireland. However, imports of other high-protein feedstuffs from non-EU regions increase, notably soybean cake from Brazil and North America. The increase in import demand for feedstuffs reflects that the higher concentrate demand from expanded cattle production exceeds the substitution effect between grass and feed concentrate in feed use. Demand for feed concentrate at EU level in the cattle sector increases by 0.18% in 2030, relative to the baseline. This unwanted side effect from the subsidy shift increases the EU's dependence on imported proteins and generates LUC and related GHG emissions, mainly outside the EU in major feed exporting countries. For instance, results show that the resulting emissions decrease of 8.45 Mt CO_2-eq from LUC effects in the EU comes with an increase of LUC emissions by 102.52 Mt CO_2-eq in Brazil and by 129.17 Mt CO_2-eq in North America. Such leakage effects that occur in non-EU countries reduce the global mitigation potential of this strategy by 348 Mt CO_2-eq or 40%. Carbon leakage as mediated by international trade has been widely discussed in global environmental assessments of agricultural sector. However, few studies so far also consider ILUC when addressing GHG emissions reduction potentials in livestock, as the majority use farm scale models (Schils et al. 2007) or have a limited regional coverage (Jansson and Säll 2018). Fellman et al. (2018) address different challenges that impede the EU agricultural sector to contribute to climate change mitigation. They find that a GHG emission reduction targeting non-CO_2 emissions from agriculture may lead to considerable carbon leakage due to changes in agricultural trade balance. In their study, this effect stems essentially from global re-allocation of the livestock sector as 90% of the additional emissions outside the EU stem from meat production. From the consumption side, Zech and Schneider (2019) estimate that the mitigation potential of a carbon tax on EU food consumption is decreased by 43% due to carbon leakage.

5.3 *Methodological contribution and limitations*

A major contribution of this study is the link of the physical MRIO model FABIO (Bruckner et al. 2019a) to the dynamic GTAP-RDEM model (Britz and Roson 2018; Roson and Britz 2021). This offers a powerful framework to increase the sectoral resolution of the GTAP database with regard to agri-food sectors. In this study, FABIO is used to increase the agri-food resolution of the original GTAP 10 data (Aguiar et al. 2019) from 21 to 31. This significantly enhances the analysis of trade-mediated effects in the EU and across the world. The integration of physical MRIO data into the data base of CGE model consisting of economic transaction poses methodological and empirical challenges (Walmsley et al. 2014; Wiedmann et al. 2011). This entails, for instance, finding appropriate price vectors to translate physical quantities into economic flows. The link to FABIO can be easily expanded to disaggregate other agri-food sectors to study both supply- and demand-driven shocks to the global agri-food system within the CGEBox framework (Britz and van der Mensbrugghe 2018). Indeed, an improved version of this link by Britz (2022) increases the agri-food detail to around 50 sectors.

Combining GTAP-based CGE models with MRIO databases is not yet common in the literature, where only a few examples can be found. One of them is the GTAP-supply chain (GTAP-SC) model (Walmsley et al. 2014; Carrico et al. 2020). GTAP-SC uses the GTAP-based MRIO database (Hertwich and Peters 2009) that employs the Broad Economic Classification (BEC) of the United Nations to differentiate between bilateral trade for intermediate use and for final consumption, at the 6 digit harmonized system (HS) level. Carrico (2017) further improved the GTAP-SC model (Walmsley et al. 2014) by introducing tariff rate differentiation across economic agents. However, the GTAP-MRIO does not provide additional agri-food sector detail beyond the 21 sectors found in the standard GTAP database. A study by Bruckner et al. (2019b) highlights the importance of increasing sectoral resolution for assessing environmental sustainability, especially in the context of an expanding global bioeconomy, which is characterized by complex and highly fragmented bio-based value chains, with high potential to generate land use spillovers and associated environmental footprints.

Some limitations of our study need to be considered. A critical aspect are uncertainties in the parameterization of the production functions of the crop and livestock sectors which may significantly affect results. Pelikan et al. (2015) therefore change the structure of the supply for primary agriculture in special version of the GTAP model such that it captures at EU level the supply response side of the farm type layer of the CAPRI model, which provides high details of the EU agriculture (Gocht and Britz 2011). Simulated output prices are then exogenously fed back into the CAPRI supply models. Such a consistent and structural “hard linkage” approach, as described in Philippidis et al. (2017) may significantly improve obtained results. Moreover, it allows for more detailed environmental assessments of the “tax recycling strategy” at the NUTS-2 EU level. The aggregation level of AEZs at country or even group of countries level in our approach might provoke aggregation bias, for instance, with regard to carbon stock accounting. A comprehensive review by Hertel et al. (2019) comprises further examples of global economic models, which try to improve the accounting of direct and indirect LUC, such as the PE GLOBIOM-Brazil model (Buurman et al. 2015; Soterroni et al. 2018), adapted from the global economic model GLOBIOM to assess land use policies in Brazil at high regional resolution. In this model, land use change and related agricultural production are presented at the grid level.

6 Summary and conclusions

This study employs a recursive-dynamic CGE modelling framework with higher agri-food detail for sectors oilseeds, vegetable oils and cakes compared to the GTAP Data Base, by dis-aggregation based on the physical MRIO data base FABIO.

The CGE model is applied to assess market-mediated impacts, including global LUC and GHG emissions, of a budget neutral redistribution of subsidies from cropland to pastureland in the EU, which aims at promoting extensive cattle production in the EU. The resulting adjustments in subsidy rates vary significantly across EU Member States, with lower increases where rates are already high in the baseline scenario, such as in Ireland.

The redistribution of land-based subsidies provokes significant changes in agricultural markets across the EU. As expected, cattle production increases in almost all EU Member States, while crop production drops. This results in an increase in crop and feed concentrate prices, which translates into reduced output of intensive animal production sectors, mainly pig and poultry, which rely on concentrate feed to a larger extent compared to cattle. Shifting overall more subsidies in the EU livestock sector increases slightly its feed concentrate demand, despite increased pastureland area. The higher feed demand combined with reduced crop production in the EU let many EU Member States increase their imports of grains and oilseeds from major global agricultural producers, with largest impacts on soybean cake imports from Brazil and North America. The subsidy shifts therefore increase the EU's reliance on crop protein imports, instead of reducing it.

Some larger ILUC spillovers of the subsidy shifts in the EU are found in the EU's main agricultural trade partners. For instance, an expansion of cropland area at the expense of unmanaged forests is observed in North America and Brazil. Regions with a low agricultural trade integration with the EU show limited LUC effects, such as Sub-Saharan Africa. In terms of GHG emissions, the policy increases global CO_2 and non-CO_2 emissions, mainly from increased CH_4 emission by the cattle sector where subsidies increase. LUC spillovers generate carbon leakage effects in major EU trade partners, such as in Brazil and North America. The net effect on global GHG emissions is still a limited global decrease, as carbon stock changes in the EU offset changes in CO_2 and Non-CO_2 emissions and from ILUC outside the EU.

The subsidy shifts go in line with the CAP's aim to improve the environmental sustainability of livestock production, as it is expected to prevent pastureland degradation and increase carbon sequestration. Enhanced production technologies and management practices, especially targeting reduced enteric fermentation in cattle production, could mitigate the main dis-advantage of the analyzed subsidy shifts, namely the increase of non-CO_2 emissions from EU cattle production. The study underlines that spillover effects by international trade can be important and need to be considered when shaping regional specific policy strategies.

This study illustrates the advantages of bringing the detail of FABIO as a specialized MRIO database into CGE analysis. Still, a better specification of bilateral trade information, as for instance found in Britz (2022), and an increase in the spatial resolution is desirable to improve the analysis of fragmented global bio-based supply chains.

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Appendix A. Supplementary data

Table A1. Regional aggregation (36 regions)

GTAP Region	Description	GTAP Region	Description
Austria	Austria	Slovakia	Slovakia
Belgium	Belgium	Slovenia	Slovenia
Bulgaria	Bulgaria	Romania	Romania
Czech Republic	Czech Republic	Estonia	Estonia
Denmark	Denmark	Latvia	Latvia
Germany	Germany	Lithuania	Lithuania
Spain	Spain	Rest of EU28	Cyprus, Luxembourg, Malta, Croatia
Finland	Finland	Australia, New Zealand	Australia, New Zealand, Rest of Oceania
France	France	East Asia	China, Hong Kong, Japan, Korea, Mongolia, Taiwan, Rest of East Asia, Brunei Darussalam
Italy	Italy	Southeast Asia	Cambodia, Indonesia, Lao People's Democratic Republ, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Rest of Southeast Asia
United Kingdom	United Kingdom	South Asia	Bangladesh, India, Nepal, Pakistan, Sri Lanka, Rest of South Asia
Greece	Greece	North America	Canada, United States of America, Mexico, Rest of North America
Netherlands	Netherlands	Brazil	Brazil
Sweden	Sweden	Argentina	Argentina
Poland	Poland	Latin America	Dominican Republic, Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Rest of South America, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Rest of Central America,
Portugal	Portugal	Middle East and North Africa (MENA)	Oman, Israel, Bahrain, Iran Islamic Republic of, Jordan, Kuwait, Qatar, Saudi Arabia, Turkey, United Arab Emirates, Rest of Western Asia, Egypt, Morocco, Tunisia, Rest of North Africa
Ireland	Ireland	Sub-Saharan Africa (SSA)	Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal, Togo, Rest of Western Africa, Central Africa, South Central Africa, Ethiopia, Kenya, Madagascar, Malawi, Mauritius,

Hungary	Hungary	Rest of World	Switzerland, Norway, Rest of EFTA, Albania, Belarus, Russian Federation, Ukraine, Rest of Eastern Europe, Rest of Europe, Kazakhstan, Kyrgyztan, Rest of Former Soviet Union, Armenia, Azerbaijan, Georgia, rest of the world

Table A2. Changes in land subsidies [1] after the tax-recycling strategy, for selected agricultural sectors.

	Cattle sector		Rapeseed		Wheat		Cereal grains nec[2]	
	Original rate	Change	Original rate	change	Original rate	change	Original rate	change
Austria	0.54	45.97%	0.76	-1.97%	0.68	-2.20%	0.77	-1.94%
Belgium	0.11	213.06%	0.3	-1.60%	0.1	-4.96%	0.08	-5.74%
Bulgaria	0.36	122.12%	0.27	-1.44%	0.27	-1.45%	0.29	-1.34%
Czech Republic	0.28	175.54%	0.34	-2.47%	0.35	-2.35%	0.36	-2.30%
Denmark	0.16	196.56%	0.18	-26.00 %	0.23	-27.55 %	0.23	-21.55%
Germany	0.53	52.18%	0.61	-1.08%	0.58	-1.13%	0.65	-1.02%
Spain	0.26	185.54%	0.27	-14.62%	0.24	-16.82%	0.26	-15.58%
Estonia	0.31	167.02%	0.31	-0.31%	0.25	-0.38%	0.27	-0.36%
Finland	0.5	58.17%	0.85	-1.16%	0.88	-1.12%	0.86	-1.15%
France	0.23	181.49%	0.29	-18.88%	0.23	-23.61%	0.28	-19.10%
Italy	0.24	199.52%	0.19	-2.59%	0.2	-2.54%	0.26	-1.90%
Greece	0.35	117.16%	0.4	-5.19%	0.33	-6.25%	0.34	-6.02%
Latvia	0.3	168.99%	0.5	-2.00%	0.48	0.30%	0.53	0.27%
Lithuania	0.39	109.85%	0.59	-0.68%	0.46	-0.87%	0.46	-0.86%
Netherlands	0.06	179.57%	0.91	-0.09%	0.08	-0.94%	0.25	-0.31%
Sweden	0.51	56.84%	0.66	-1.60%	0.5	-2.11%	0.5	-2.09%
Poland	0.21	196.88%	0.2	-1.20%	0.23	-1.07%	0.24	-0.99%
Portugal	0.29	147.19%	0.41	-17.11%	0.24	-29.30%	0.39	-18.19%
Ireland	0.71	6.96%	0.76	-4.44%	0.71	-4.76%	0.64	-5.30%
Hungary	0.29	169.17%	0.36	-4.97%	0.29	-6.30%	0.36	-5.06%
Slovakia	0.28	138.40%	0.28	-50.05%	0.27	-51.32%	0.28	-49.99%
Slowenia	0.23	187.92%	0.44	-6.14%	0.35	-7.60%	0.4	-6.65%
Romania	0.16	189.06%	0.26	-7.90%	0.22	-9.56%	0.25	-8.31%
Rest of EU28	0.31	151.45%	0.46	-3.78%	0.3	-5.77%	0.32	-5.53%

[1]*GTAP uses ad valorem taxes.* [2]*Not elsewhere cited.*

Table A3. Changes in production and price of major feed crops across the European Union (EU28) in 2030 relative to the baseline (%)

	Rape seed		**Other oilseeds**	**Legumes**		**Wheat**		**Other grains**	**Cereal**
	Quantity	Price	Quantity	Quantity	Price	Quantity	Price	Quantity	Price
Austria	-0.45	1.60	1.1	-0.95	2.27	0.26	1.57	0.08	1.58
Belgium	1.2	1.71	0.58	6.68	2.23	0.74	1.51	0.3	1.62
Bulgaria	-0.75	2.00	-0.63	-1.17	2.97	0.19	1.79	-1.63	2.53
Czech Republic	1.23	0.78	2.26	2.57	2.73	2.61	0.63	1.21	0.31
Denmark	2.68	1.21	2.75	12.86	2.34	1.01	1.31	0.66	1.30
Germany	0.67	1.59	0.17	2.15	2.84	0.87	1.63	0.05	1.54
Spain	-0.76	1.87	-0.75	-0.22	3.08	-0.06	1.81	-0.11	1.78
Estonia	-1.26	2.39	-0.09	-4.8	3.08	-2.81	2.53	-1.69	2.51
Finland	1.71	1.65	-0.05	0.83	1.53	0.23	1.56	0.1	1.53
France	0	1.73	-0.05	-0.88	2.78	-0.44	1.91	-0.18	1.85
Italy	2.4	1.36	2.23	5.27	3.02	0.79	1.38	0.4	1.41
Greece	-9.13	4.04	-4.53	-6.87	4.92	-2.17	2.02	1.23	1.54
Latvia	-7.48	3.00	-10.92	-0.88	2.53	-6.13	2.95	-4.02	5.34
Lithuania	-8.42	3.62	-13.42	-1.49	2.96	-7.09	2.95	-3.23	3.61
Netherlands	2.23	1.37	2.7	8.26	1.81	3.1	1.17	1.16	1.18
Sweden	0.66	1.55	0.47	0.31	1.87	0.93	1.51	0.33	1.49
Poland	2.23	1.03	0.36	5.79	1.14	0.91	1.52	0.36	1.43
Portugal	0.19	1.71	0.47	5.12	5.01	0.08	1.74	0.07	1.73
Ireland	3.62	1.28	2.61	1.41	2.20	0.7	1.46	0.84	1.50
Hungary	0.39	1.57	0.87	5	2.19	1.85	1.24	0.37	1.56
Slovakia	-1.77	1.74	-1.03	-0.51	4.28	-2.17	1.84	-1.01	2.05
Slowenia	-1.58	1.96	-1.61	0.28	3.07	-1.27	1.80	-0.49	1.92
Romania	0.95	1.91	0.21	0.18	3.39	-0.64	1.92	-0.04	1.91
Rest of EU28	-0.38	1.88	0.24	0.68	2.77	-0.66	1.89	-0.35	2.10

Table A4. Changes in land rents (net prices after tax) in 2030 [change relative to the year 2014]

	Rape seed	Wheat	Cereal grains nec	Cattle	ALL sectors
Austria	-1.89%	-1.44%	-2.03%	19.40%	0.24%
Belgium	0.79%	1.53%	1.21%	6.54%	1.60%
Bulgaria	3.34%	2.96%	1.34%	29.48%	2.45%
Czech Republic	-0.18%	0.64%	-1.06%	39.89%	-0.33%
Denmark	-3.06%	-1.25%	-1.61%	6.51%	-2.80%
Germany	0.13%	0.60%	-0.39%	20.69%	0.31%
Spain	-1.25%	0.24%	0.15%	31.44%	0.89%
Estonia	8.50%	6.60%	7.88%	42.36%	5.22%
Finland	-2.15%	-4.27%	-3.97%	19.72%	-0.33%
France	-3.05%	-1.52%	-1.60%	21.70%	0.03%
Italy	-0.33%	-0.97%	-0.88%	20.72%	-0.88%
United Kingdom	0.27%	2.41%	2.39%	1.18%	1.67%
Greece	1.94%	11.25%	15.44%	50.05%	9.72%
Latvia	-2.39%	-0.84%	2.34%	41.38%	4.25%
Lithuania	-0.54%	0.30%	4.97%	34.57%	4.70%
Netherlands	-2.62%	-1.91%	-3.85%	-2.92%	-2.01%
Sweden	-0.18%	0.48%	-0.07%	21.47%	-0.02%
Poland	-3.14%	0.70%	0.09%	16.65%	-1.21%
Portugal	-6.07%	-3.66%	-4.82%	23.55%	-2.19%
Ireland	-0.46%	-2.30%	-1.27%	9.91%	0.76%
Hungary	-3.99%	-1.61%	-3.18%	28.03%	-2.13%
Slovakia	-13.90%	-13.96%	-13.12%	17.43%	-6.57%
Slowenia	-2.40%	-1.17%	-0.38%	19.44%	0.21%
Romania	1.52%	-0.14%	0.57%	18.28%	1.33%
Rest of EU28	-1.13%	-1.23%	-0.85%	26.52%	0.07%