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Agrifood Economics Centre working paper

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Abstract

Subsidizing polluting industries generally leads to increased pollution. However, given the diversity of production technologies across countries and international trade, the overall impact of unilateral policies is not a-priori clear. We use the agricultural sector model CAPRI to simulate the impact of removing the voluntary coupled support (VCS) for ruminants permitted under the present Common Agricultural Policy. Findings are that this reduces beef production and GHG emissions in the EU. Emission leakage significantly diminishes the global impact since emission reduction in the EU to a large extent (about 3/4) is offset by increased emissions in the rest of the world.

Keywords: CAPRI, greenhouse gas emissions, voluntary coupled support, ruminants, climate change

1. Introduction

In the Paris Agreement on Climate Change, greenhouse gas (GHG) emissions reductions in the agricultural sector are highly prioritised and most countries have expressed willingness to contribute to such reductions (FAO, 2016). Moreover, the latest communication of the European Union (EU) Commission on the future of food and farming emphasises the need for future Common Agricultural Policy (CAP) support to farmers to be conditioned on their undertaking environment- and climate-friendly practices (European Commission, 2017a). However, the policies for the agricultural sector in the EU, which is regulated through the CAP, are not specifically designed to comply with climate policies (Erjavec et al., 2017). Current policies affect agricultural production volumes and production practices, some by increasing GHG emissions (e.g. subsidies for fossil fuel, subsidies for ruminants), and thus contribute to climate change. Under the present CAP, most support consists of direct payments to farmers, on a per-hectare basis, for all qualifying agricultural land. These payments are decoupled from production, and member states are obliged to harmonise them across regions (European Union, 2013). However, member states are free to introduce coupled support for selected sectors within agriculture, up to a ceiling of 13% of the total direct payment envelope in most cases. This *voluntary coupled support* (VCS) is used by almost all member states to aid certain sectors undergoing economic, social or environmental difficulties in maintaining/increasing production, to a large extent targeted at cattle and other ruminants (European Commission, 2017b).

As the livestock sector (ruminants in particular) has the highest GHG emissions intensity and total emissions within agriculture (e.g. Lesschen et al., 2011, Golub et al., 2013), GHG emissions are affected by VCS. Conversely, removing VCS would reduce profitability and thus production, but also associated GHG emissions in the EU. As the products are traded on a global market, the decline in domestic production would cause an increase in import demand, a reduction in export supply and thus a rise in prices on the world market. This in turn would provide incentives to increase production outside the EU. In other words, part of EU ruminant production and associated emissions would move abroad, causing so-called *emissions leakage*, as discussed by Markusen (1975), Zhang (2012). This emissions leakage could be expected to offset emissions reductions obtained in the EU, or even lead to an increase in total global emissions. It is thus important to take emissions leakage into account when re-designing policies to reduce the climate impact of the agricultural sector. The impact of policy changes on global GHG emissions, specifically the effect of removing VCS, is not clear *a priori*. Therefore, in this study we assessed emissions leakage resulting from removing VCS, using the agricultural sector model CAPRI (Common Agricultural Policy Regionalised Impact) (Britz and Witzke, 2014). The intention was to examine the impact of coupled support on agricultural production and climate.

There are several reasons why the agricultural sector is of particular interest for climate policies. The main reason that it is exempted from the EU emissions trading system (EU-ETS), which is a cornerstone of the EU efforts to limit global warming. The EU-ETS covers most sectors, but some have been exempted and some have been granted special treatment due to concerns about the risk of leakages or due to difficulties in monitoring emissions in the sector (European Commission, 2016). The agricultural sector qualifies for special treatment on both these counts. However, the sector also has largely unused potential to reduce GHG emissions and is an important source and sink of carbon (Allen and Maréchal, 2017, Grosjean et al., 2016). The contribution of the agricultural sector to total global GHG emissions (methane (CH_4) and nitrous oxide (N_2O))[1] was between 10 and 12% in 2010 (rising to 24% when emissions from energy and land use for agriculture and forestry, other uses are included) (Smith et al., 2014). In the EU, direct agricultural emissions comprised about 10% of total

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[1] Following the common format reporting of the United Nations Framework Convention on Climate Change (UNFCCC), the category agriculture only includes nitrous oxide and methane. Carbon dioxide emissions (CO_2) for land use, land use change, forestry, and energy consumption at farm level are attributed to other sectors.

GHG emissions in 2015 (European Environment Agency, 2017). The emissions intensity, i.e. the amount of emissions per tonne of product, varies widely across time and space and depends on different biological processes for each product (IPCC, 2006).

A few previous studies have considered emissions leakage within the agricultural sector, but to the best of our knowledge the impact on global GHG emissions of EU production subsidies within the CAP has not been analysed previously. Fellmann et al. (2012) and Fellmann et al. (2018) used CAPRI to simulate EU-wide reductions in GHG emissions of 20% and 28% by 2020 and 2030, relative to 2005, in response to global climate agreements, in the latter case the Paris Agreement of 2016. Specific policy changes were not investigated, but the model sought an optimised change in production quantities and methods to reach different potential emissions reduction targets in each member state. One of the findings was that the reductions in GHG emissions in the EU were accompanied by significant emissions leakage. Lee et al. (2007) used the GHG version of the U.S. Agricultural Sector Model (ASMGHG) to simulate the welfare impact and emissions leakage from unilateral, partial global and full global implementation of mitigation policies related to emissions reduction actions on agricultural production and international trade. They found that, under a unilateral policy, total GHG emissions decline but substantial emissions leakage occurs. Van Doorslaer et al. (2015) found that emissions leakage can significantly reduce the benefits of emissions reductions in the EU, depending on *how* climate policies are implemented in the EU. This implies that a policy efficient in reaching climate objectives, e.g. in reducing GHG in the EU, may not be the best way to reduce global emissions, even when the policy space is limited to measures that can be implemented by the EU. Reviewing the literature, Zhang (2012) found that most models predict significant leakage effects (for all sectors), but that it is difficult to establish specific effects, e.g. from the EU ETS. This could be due to missing factors in the models, such as exclusion of endogenously changing technology and spillover effects, and limitations in the data available.

The aim of the present study was to investigate the impact of the EU CAP measures on GHG emissions in a global perspective. Specifically, using the CAPRI model we simulated the effect of removing the VCS to ruminants and assessed the impact on production, prices and emissions. Furthermore, in order to identify the causes of emissions leakage, we decomposed the changes in emissions into production-level effects and reallocation effects. A deeper understanding of the causes of emissions leakage is important so that policy interventions can be directed towards those parts of the economy that give the greatest positive global effect on GHG emissions. In this study we analysed scenario results to be used for: i) assessment of the new CAP reform in 2020 and ii) development of strategies for implementation of the EU's new target of at least 40% reduction in domestic GHG emissions by 2030 (European Environment Agency, 2015), in compliance with the global climate goals in the Paris Agreement to limit global warming.

The remainder of the paper is structured as follows. Section two describes the CAPRI model, estimation of GHG emissions, the European agricultural policy context and the scenarios applied. The results are presented in section three and discussed in section four, which also presents some conclusions and policy recommendations.

2. Methodology

Assessment of the impact on global GHG emissions from agriculture was based on: 1) the policy impact on global agricultural production and trade and 2) the impact on global GHG emissions from agriculture following from these changes and thus caused by the policy.

2.1. The CAPRI modelling system

This section gives a brief description of the CAPRI model and some details on modelling global trade using the model. Computation of GHG emissions is described in the next section.

The CAPRI model is a partial equilibrium simulation model covering the agricultural sector (Britz and Witzke, 2014). The model simulations provide results for the global impact on production and trade in the agricultural sector, aggregated to about 40 trade blocks, and detailed results for NUTS2 (Nomenclature of Territorial Units for Statistics) regions within the EU. The CAPRI model is frequently used to assess the impact of changes in the CAP on e.g. production, trade and selected environmental indicators. Some recent examples are simulations of the impact of currently proposed EU free trade agreements and carbon taxes on GHG emissions (Himics et al., 2018), simulations of the impact of the so-called Greening in the CAP reform 2013 (Gocht et al., 2017) and used together with other models, to simulate the impact of climate change on agriculture (Blanco et al., 2017). As the CAPRI model contains a detailed representation of the EU agricultural sector, including agricultural policy measures used under the CAP and trade in agricultural products, it provides a suitable base for estimating the impact of unilateral (EU) policy changes on global GHG emissions. CAPRI have in been used to study climate policy earlier (Fellmann et al., 2018, Pérez Domínguez et al., 2009, Himics et al., 2018).

CAPRI is a comparative static model, meaning that the policy impact is inferred from a comparison of a baseline and a policy scenario at a specific point in time. In the present study, this point in time was set at 2030, after the end of the next multiannual financial framework[2]. The CAPRI baseline is based on the Agricultural Outlook published by the European Commission.

The model consists of a supply module and a global market module. The supply module covers EU member states and some selected neighbouring countries[3] (hereafter called EU+). This module consists of one independent *representative farm* for each NUTS2 region in the EU or corresponding administrative level in the neighbouring countries. Each representative farm maximises regional agricultural income at given prices and subsidies, subject to constraints such as policy variables, feed and plant nutrient requirements and land availability in each region. Land is endogenous and the total available agricultural land can thus vary across scenarios.

It is assumed that farmers are price-takers, i.e. prices are fixed from the perspective of the farmer. Nevertheless, all farms together do influence EU and world market prices. Prices, demand, trade and some processing activities are modelled by a dedicated market module that covers 47 primary and secondary agricultural products in about 80 regions globally. In the market module, where countries outside the EU+ are represented, agricultural production is modelled in a simplified fashion compared with the supply module. To model bilateral trade, the 80 regions in the market module are aggregated to about 40 market regions (such as the EU). Trade flows between those 40 regions are modelled based on the Armington assumption of quality differentiation. In addition, detailed trade policy data on Most Favoured Nations and on Preferential Tariff Rates, Tariff Rate Quotas and the trigger price system of the EU are incorporated in the module.

A detailed representation of the policy measures of Pillar I in the CAP and a less detailed representation of measures in Pillar II are incorporated in the supply module, thus making it suitable for analysing the impacts of agricultural policy reform scenarios. A scenario such as removing VCS would affect production decisions in the EU, which in turn would affect prices and thus consumption, trade and production outside the EU. Based on the outcome in production, the impact on GHG emissions for the 80 global regions can be computed, and in the EU+ regions emissions in NUTS2 regions are computed.

2.2. GHG emissions in CAPRI

CAPRI has a global coverage of GHG emissions, but the method used to calculate emissions varies depending on the availability of detailed production data from the simulations. For the EU+ countries, more details on production are available than for regions only covered by the market module. For all

[2] The duration of the multiannual financial framework is not yet decided, but could be 5-10 years after 2020 (European Commision, 2017).
[3] Turkey, Balkan countries and Norway

regions, main direct and indirect emissions of methane (CH_4) and nitrous oxide (N_2O) from agriculture are covered (representing agricultural emissions according to the UNFCCC classification). The emissions from land use, land use change, fertiliser production and energy use on farm are omitted from our analysis as they are not yet covered globally CAPRI. This is a limitation, but as we expect our scenario to affect land use only indirectly while CH_4 and N_2O directly, they are more relevant for the present study. A full list of GHG emissions sources covered in our analysis is presented in the appendix (Table A1). To compare emissions of different gases, Global Warming Potential (GWP) was used to convert all gases into carbon dioxide equivalents (CO_2-eq).[4]

In the supply module in CAPRI, emissions are calculated endogenously based on detailed input and output data. This means that e.g. changes in the feed mix for animals due to a policy change can be captured when changes in emissions are calculated. For the main emissions sources, the calculation is performed using a more detailed method (Tier 2 in the IPCC (2006) guidelines), while for some sources with less total contribution to emissions a simplified method (Tier 1) is used. Thereafter, emissions are allocated to commodities associated with each agricultural activity. A more detailed description of the method is available in Leip et al. (2010), Pérez Domínguez (2005) and Pérez Domínguez et al. (2012).

For regions outside the EU+, the same level of detail in the data is not available. Therefore exogenous emissions intensities, i.e. emissions of GHG in CO_2-eq per tonne of product, are calculated directly for specific products. This means that the production technology and use of inputs are assumed to remain unaffected outside the EU+ by a policy change in the EU. Product-based emissions coefficients are estimated to reflect the overall agricultural emissions reported in GHG inventories. To calculate changes in total emissions, the emissions coefficients are multiplied by production changes in the simulations. To cover agricultural GHG emissions globally, we estimate production based emission coefficients for all the commodities and all regions in the market module, and the main GHG emission sources within the agricultural sector (in the UNFCCC classification). The emission coefficients are estimated so that for given data on production of agricultural commodities, they fit data on total GHG emissions for each emission source as closely as possible over time.

Each emission coefficient is defined by a trend function to capture that emission intensities are changing even though this is not endogenously modelled as for regions in the supply module. An inverse function is used for the trend.

Emission coefficient trends for commodities are estimated individually for each region and emission source. In many cases, the number of different commodity is high compared with the number of years for which there is data. If so, the degrees of freedom of the estimation can become small or negative. In order to improve robustness a Bayesian estimation framework was developed that allows us to utilize *prior information* on the emissions coefficients. The prior information is expressed in the form of probability distributions, to be interpreted as what we would expect the value to be before seeing the present data sample (e.g. Koop, 2003, pp 15).

We use GHG inventory data from FAOSTAT (Statistic Division of Food and Agriculture Organization of the United Nations) provided for each emission category and region. Data on production quantities are taken from the CAPRI database, where the underlying data is from FAOSTAT. In most cases the data covers the period 1990-2009, while in some cases fewer years are available. Regions are aggregated to regional units used in CAPRI, and FAO-commodities are aggregated to commodities used in CAPRI.

Prior values for the emission factors are derived from various sources. In a first case they are taken from expert judgement from Leip et al. (2010). Second we construct priors for many commodities and emissions sources with data on activity levels and production levels from the year 2014 version of the

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[4] The conversion factor used is 28 for methane and 265 for nitrous oxide, from the latest IPCC report (AR5) with 100 year time-horizon, without inclusion of climate–carbon feedbacks (Myhre et al., 2013)

AGLINK-COSIMO model (for a description of the model, see (OECD, 2015)). Emissions per activity data is calculated by the Tier 1 methodology in the IPCC Guidelines (IPCC, 2006, IPCC, 1997), and then converted to emissions per product. Third, average EU emission coefficients that are calculated in the supply module in CAPRI are used as priors.

2.3 Decomposition of emissions leakage

As the amount of emissions per tonne product varies across regions and emissions leakage is influenced not only by the production change, but also by the reallocation to regions with differing emission intensity. When production is reallocated to regions with higher emissions intensities, the total emissions will increase for a given level of production. To identify the impact *caused by production change*, only, we set the emissions intensity to equal the *global average in the reference scenario* for all countries and thereafter calculated the emissions using the production changes in the policy scenario. This would be equal to *only* changing global production levels, while netting out any effects from a modified regional distribution of this production. The calculated changes, i.e. changes due to production levels, were subtracted from the total global changes in GHG emissions observed, giving the emissions changes *caused by reallocation* of production to regions with different GHG emissions intensity.

2.4 Agriculture in the EU 2030

The CAPRI baseline projects agricultural production and emissions to the year 2030 under a business-as-usual scenario. This means that the CAP is assumed to be unchanged. Within the CAP, the largest part is Pillar I measures, which mainly involve support and some market intervention schemes. Pillar II covers both support to agricultural production and rural development. Only the former is included in CAPRI as only agricultural production is modelled. Within Pillar I, support is paid on a per-hectare basis and is converging to more equal payments in and between member states by 2030. Several different support schemes exist within Pillar I. The largest is the Basic Payment Scheme (or the Single Area Payment Scheme for some regions), with support allocated to all agricultural land with entitlements. The Greening payment, which has associated constraints on e.g. crop diversification and keeping ecological focus areas, constitutes another large part, while a smaller part of Pillar I has to be directed to payments to young farmers. It is optional for the member states to direct some part of the Pillar I budget payments to the first hectares (meant as a redistributive payment), simplified schemes for small farmers, payments to areas with natural constraints and VCS. In addition, there is crop-specific coupled support for cotton in some countries and complementary National Direct Payments in some countries. VCS, the focus of the present study, permits member states to use up to 13%[5] of the Pillar I payments for coupled support to specific sectors that are deemed to be vulnerable or important, on a per-head or per-hectare basis. VCS is largely granted to beef and veal and other ruminants. For beef and milk, VCS would constitute 4.1% and 0.8%, respectively, of total revenues (revenues + support) in 2030.

As noted, most VCS is dedicated to beef, but in terms of meat production in the EU beef only contributes 16%, while meat from other ruminants (sheep and goat) contributes another 2% and the rest is pork and poultry meat. Ruminants thus represent a relatively small proportion of meat production, but they also produce milk. However, in terms of emissions coefficients (EU average), one tonne of beef meat is estimated to emit about 9 times as much as one tonne of pork, while emissions coefficients for food crops are significantly lower. This clearly demonstrates the high emissions intensity of ruminant products compared with other forms of agricultural production.

2.5 Simulated scenarios

The impact of a policy change in 2030 was derived by comparing the outcome of a *reference scenario,* assuming business as usual, to a policy scenario. Key results from the model are GHG emissions, production and trade patterns. In the reference scenario, the current CAP was assumed to

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[5] The exact maximum depends on the circumstances (European Commission, 2017b).

continue until 2030. This scenario also included projected exogenous changes in the world, such as population growth and changes in demand. The *policy scenario* was similar to the reference scenario, but VCS to ruminants was removed. In the CAPRI model, these subsidies are implemented as a direct subsidy per head, with budgetary ceilings as reported by EU countries. The released budget funds from VCS were reallocated to the other direct payments in each member state, which meant that the total support in each member state was similar in the reference and policy scenarios. The redistribution of support in the policy scenario resulted in an average increase in per-hectare payments for agricultural land (including fodder) of 6.5% in the EU, while support directly to beef cattle decreased by 69% per head, that for dairy animals by 41% per head and that for sheep and goats by 36% per head. The remaining support consisted of national payments such as Nordic Aid and Pillar II payments.

3. Results

3.1. Global changes in emissions of GHG from agriculture

When VCS to ruminants was removed, emissions in the EU, but also outside the EU, were affected. Table 1 shows total agricultural GHG emissions in kt CO_2-equivalents in the reference scenario and the changes in emissions between that and the policy scenario, i.e. with simulated removal of VCS, for 2030. With the policy change, the GHG emissions in the EU decreased by 2095 kt. However, there was an emissions leakage effect, as emissions in the rest of the world increased by 1512 kt. This resulted in a net decrease on a global basis of 583 kt, or approximately 28% of the emissions decrease in the EU. Changes occurred in all countries, but some accounted for a larger share of the changes in emissions within and outside the EU. In the EU, the largest decrease in GHG emissions in absolute terms was found for France, Spain and Poland. In EU countries such as the United Kingdom, Ireland and Germany, where ruminant production receives little or no VCS, GHG emissions increased, because in these regions ruminant herds slightly increased. Outside the EU, the countries with largest absolute contribution to the change in agricultural GHG emissions were Brazil, Argentina and India. The changes in agricultural GHG emissions for the key countries are presented in the appendix (Table A2).

Table 1. Impact of removal of voluntary coupled support (VCS) for ruminants on agricultural greenhouse gas emissions (kt CO_2-equivalents) in European Union (EU) and non-EU countries and in the world

	EU		**NON-EU**		**WORLD**	
	Reference scenario	*Change under policy scenario*	*Reference scenario*	*Change under policy scenario*	*Reference scenario*	*Change under policy scenario*
Total agric. prod	435 244	-2 095	6 282 640	1 512	6 717 884	-583
Beef	129 290	-1 889	2 660 179	1 385	2 789 468	-504
Raw milk	175 345	-268	1 309 204	-3	1 484 549	-272
Goat and sheep meat	19 754	-68	643 600	188	663 354	120
Pork meat	45 236	72	201 072	-1	246 308	70
Poultry meat	7 625	13	115 650	4	123 275	17
Eggs	2 752	2	31 736	0	34 489	2
Crops	55 241	44	1 321 200	-60	1 376 440	-16

About 90% of the emissions reduction in the EU derived from production of beef, with an absolute decrease in emissions of 1889 kt CO_2-eq (Table 1). This was a result of less production, as production in relative terms decreased by 1.1% (see Table 2). As can be seen in Table 1, milk is the largest source of emissions in the EU, but the change in emissions for milk in the policy scenario was much smaller than for beef, due to a limited impact of the policy change on production of milk. For crop products, emissions barely changed. These results illustrate the heterogeneity of the impacts of VCS on global emissions from different sub-sectors. The reduction in milk production in the EU was accompanied by a global emissions reduction even larger than that in the EU, while for beef much of the reduction in the EU was cancelled out by increased emissions outside the EU. For sheep and goat meat, there was even an increase in emissions globally, despite the 68 CO_2-eq reduction in the EU in the policy scenario. The increase in emissions from substitutes for beef, such as pork and poultry, was expected, due to consumers replacing some of the now more expensive beef with relatively less expensive pork or poultry. Since emissions intensities for poultry and pork are significantly lower than for beef, this substitution was not negative *per se*. As beef meat was the largest contributor to the change in GHG emissions and the beef sector was that most affected by the removal of VCS, hereafter we focus on the results for beef.

Table 2. Impact of removal of voluntary coupled support (VCS) for ruminants on the beef market in European Union

	Reference scenario	***Policy scenario***	
	Value	Change in value	% change
Production (kt)	7 891	-83	-1.1
Consumption (kt)	7 870	-46	-0.6
Import (kt)	241	10	4.0
Export (kt)	184	-27	-14.5
Producer price (EUR per tonne)	4 371	105	2.4
Consumer price (EUR per tonne)	9 153	105	1.1

Note: Production, consumption, import and export quantities are given in thousand tonnes (kt)

In the policy scenario beef production in the EU decreased but, as the EU borders are not closed, these changes are affected by and affects trade with the rest of the world. Changes in the EU beef market are given in Table 2. As a consequence of changing production and trade, the producer and consumer price of beef meat in the EU increased, dampening production effects. Thus production decreased by 83 kt, while consumption was rather inelastic and decreased by only 46 kt. The gap between decreased production and consumption of beef was mainly maintained by a reduction in exports from the EU, and to a smaller extent by increased imports to the EU. This caused production changes in countries outside the EU, where production increased by 43 kt (Table 2). Thus the increase in global production was much more limited than the reduction in the EU.

Table 3. Impacts of removing voluntary coupled support (VCS) for ruminants in the European Union (EU) on beef production in non-EU countries and regions showing the largest changes and their trade with the EU

Country/area	Reference scenario **(quantity in kt)**			Policy scenario relative to reference **(change in quantity, kt)**		
	Production	*Import*	*Export*	*Production*	*Import*	*Export*
USA	11626.5	29.1	0	5.4	7.1	0
Brazil	10817.7	74.5	4.9	8.00	0.7	-0.8

Russia	1784.0	0	46	6.4	0	-8
Mediterranean countries *	1027.6	0.7	44.3	2	0	-8.2
Kazakhstan	449.0	0	12.8	1.4	0	-1.8
Western Balkans**	195.9	6.5	25.2	0.6	0.6	-1.3

Note: *Tunisia, Algeria, Egypt, Israel. **Albania Macedonia, Serbia, Montenegro, Bosnia and Hercegovina, Kosovo.

Imports of beef to the EU increased most from the USA, while exports from the EU decreased most for Russia (Table 3). The latter was met by a production increase in Russia. Beef exports to Mediterranean countries also decreased. Argentina and Brazil remained the main trading partners, but their exports to the EU did not change greatly. Instead, changing world market prices affected their trade with other parts of the world, resulting in large production increases in Brazil. Other regions outside the EU also changed their production and trade relations. India's production and export increased slightly, which had a large effect on global emissions as Indian production is relatively emissions-intensive (see Table A2). These results show that the European ruminant sector is affected by VCS, as are European GHG emissions.

3.2. Decomposition of emissions leakage

The results show that abolishing VCS to ruminants would have a limited effect on global agricultural GHG emissions, due to reallocation of production. To gain insights into this process, we decomposed the changes in emissions. The obvious reason for increases in emissions outside the EU is increased production of beef in countries outside the EU. Another reason is that production is more or less intense in GHG emissions at different locations, which means that *reallocation* of production has an impact on emissions. In addition, changing conditions can alter the production technology, which could affect the emissions intensity of a product. In our simulations, these technological changes were only modelled endogenously for EU+ countries.

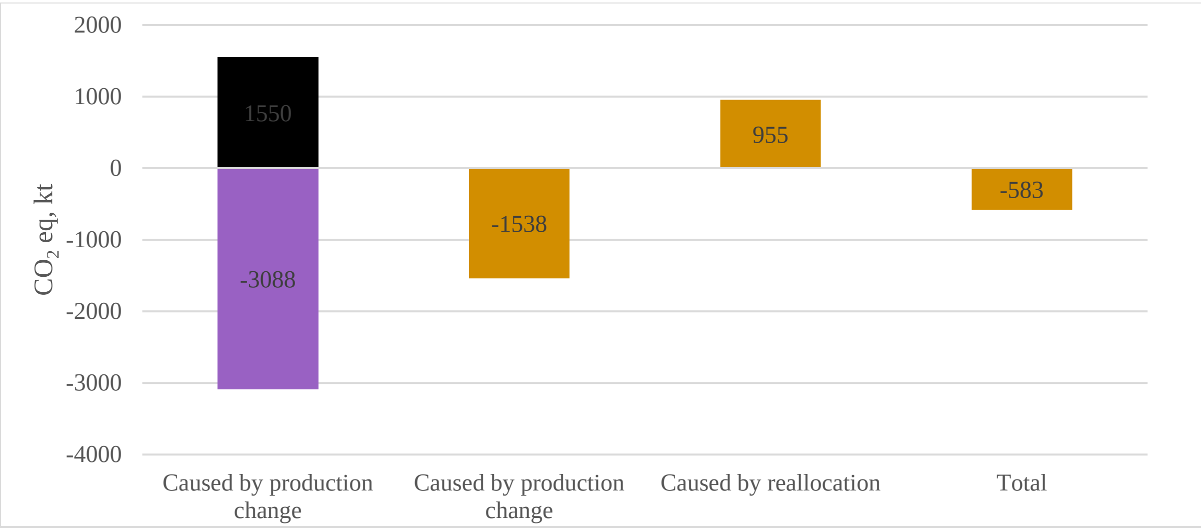

Figure 1. Global changes in greenhouse gas emissions, decomposed into those caused by production and those caused by differences in emissions intensity in producing countries.

The emissions changes for beef resulting from production volume and reallocation effects are presented in Figure 1. The bar to the left shows the emissions changes that would have occurred if the average emissions intensity in the world (from the reference scenario) applied to all regions, while the production changes remained the same. This emissions change can be attributed to the change in global production volume. The reduction in production would thus have decreased global emissions by 1538 kt CO_2-equivalents. However, the actual emissions decrease globally was 583 kt CO_2-eq, which is 955 kt less than the emissions reduction brought about by production level changes. This discrepancy is explained by reallocation of production to locations with higher emissions intensity than in the EU.

4. Summary and conclusions

Cessation of subsidies for emissions-intensive activities could be expected to reduce emissions, due to a decline in total production, and would thus contribute to limiting climate change. However, this change is not assured when products are traded and there are significant differences in production methods between countries. A reduction in subsidies in one region could shift production from less polluting production methods in that region to more polluting production methods in another region. Removing subsidies could thus cause reallocation of production to regions where emissions partly or fully cancel out the reduction in local emissions. This highlights possible leakage of emissions following unilateral climate policy measures. The agricultural sector is of particular interest in this regard, as production causes significant emissions of GHG and is affected by a broad range of policy measures in the EU. To assess the impact on global emissions of a reduction in subsidies to an emissions-intensive activity within the EU on global emissions, this study analysed the effects of removing VCS to the ruminant sector and associated emissions leakage and conflicting policy objectives, e.g. increased agricultural production and reduced climate impact.

For the analysis, the agricultural economic simulation model CAPRI was used. The analysis was limited to agricultural sector emissions of non-CO_2 gases, i.e. N_2O and CH_4, following the UNFCCC classification, so CO_2 emissions from land use, land use change, fertiliser production, transport and energy consumption at farm level were attributed to other sectors. Gerber et al. (2013) estimate that about 75% of emissions from beef production are in the form of N_2O and CH_4 and about 25% are CO_2 emissions from land use and land use change, but with large uncertainties. The effects of omitting emissions from land use and land use change on our results are unclear, as the importance of omitted emissions and production methods varies across regions. However, despite these limitations, we demonstrated changes in the key GHG emissions from ruminant production, which was the aim of the analysis. Future refinements to the CAPRI model should seek to capture other factors in agriculture impacting climate change.

Our results showed that removing VCS to ruminants in the EU would have a modest impact (-0.4%), on emissions from ruminants in the EU. Moreover, on a global scale most of this reduction (about three-quarters) would be cancelled out by increased emissions outside the EU. Hence the global impact on GHG emissions would be even less than the emissions reduction in the EU. Inelastic demand and opportunities to trade would cause a shift in production from the EU to other countries, hence the higher emissions outside the EU. Besides the impact on emissions caused by higher production volumes outside the EU, emissions would be further magnified by the emissions-intensive production methods used in countries where production might expand (e.g. Brazil and India). The reallocation from less (EU) to more emissions-intensive production technology would increase emissions leakage. This illustrates one of the problems with a unilateral policy and policies mainly affecting EU production volumes rather than production technologies and consumption. Emissions leakage means that in order to attain a specific global reduction in emissions, unilateral local policies would have to reduce emissions to a much larger extent than indicated by a unilateral objective.

Furthermore, the emissions leakage would vary across product categories. For example, the global emissions for goat and sheep meat would increase even though EU emissions declined. For beef meat, the global emissions reduction would be about 28% of the emissions reduction in the EU, while for milk the global emissions reduction would be even slightly larger than in the EU. This indicates that production subsidies for *some* products may cause more harm to climate efforts than subsidies to others, but further research on specific products is required to form a solid base for policy decisions.

Due to uncertainty in estimation of GHG emissions and limitations in modelling technological adaptation, the exact numbers presented in this paper should be interpreted with care. Nevertheless, our results clearly stress the importance of keeping emissions leakage in mind when designing policies. They also show that subsidies to the emissions-intensive ruminant segment of agriculture can exacerbate climate change. Compared with other studies on EU agriculture, the leakage effect in our analysis was quite modest, which might be a particularity of the VCS instrument. For example, Fellmann et al. (2018) found that emissions leakage effects reduced the impact of more general policies to reduce EU agricultural emissions by as much as 91%, of which about 90% was attributable to cattle. Van Doorslaer et al. (2015), also using CAPRI, found that unilateral policies aimed at reducing emissions intensities generally led to less leakage than policies setting reduction targets achieved mainly by reduced production. They also found that for more ambitious mitigation targets the leakage is generally larger, and thus the cost of achieving a global emissions reduction target by unilateral policies would increase with the level of ambition in emissions reduction targets.

The apparent inefficiency of unilateral policy to reduce global GHG emissions from agriculture due to reallocation of production is amplified by the differences in emissions intensities around the world. From a leakage perspective, when production is reallocated to more emissions-intensive production sites, this means higher emissions for a given level of production. Thus it could be useful to consider complementary policy options that limit leakage and/or reduce overall emissions intensity, rather than policy measures that mainly cause reallocation of production. The significant degree of emissions leakage shows that flanking measures which reduce this leakage, or policies which reduce consumption of highly emissions-intensive products and/or support less emissions-intensive production methods, should also be considered. Border carbon adjustment (BCA) measures are one flanking policy suggested to reduce emissions leakage, but their effect differs between industries and BCA policies (e.g. Kuik and Hofkes, 2010, Branger and Quirion, 2014). In a meta-analysis of 25 studies, Branger and Quirion (2014) showed that imposing BCA measures would decrease emissions leakage from on average 14% to 6%. Fellmann et al. (2018) suggest that measures to reduce overall emissions intensity can be particularly important in developing countries.

Spillover effects from unilateral policies and the global learning effect cannot be observed with the CAPRI model, where global policies do not change endogenously. However, (Chatterji et al., 2014) showed that unilateral policy changes for global GHG emissions mitigation can induce spillovers from countries implementing the policy, and over time strengthen policies globally and thereby reduce GHG emissions globally.

A reduction in global emissions, albeit small and despite leakage effects, achieved by not subsidising a polluting industry could be an efficient contribution to climate policy, as removing the subsidy could be expected to improve efficiency in the economy, and thus improve welfare. However, the reduction in emissions achieved should also be viewed in the context of conflicting policy objectives. The stated policy objective for VCS is to maintain important and vulnerable agricultural sub-sectors (European Commission, 2017). The scheme can be perceived as successful in this regard, as our results clearly showed that removal of the subsidy would cause a decline in production. Whether the potential benefits of VCS in terms of maintaining production in the EU justify the negative impact on the climate is an open question, but should be a key element in evaluation of the policy.

This analysis illustrates the importance of accounting for the impact on emissions globally, rather than in a country or region as is often the case with unilateral climate policies. The results show the importance of designing policies to maximise the impact on global emissions, i.e. considering leakage effects that offset local emissions reductions. The results presented in this paper can assist in formulating strategies and measures targeting reductions in global GHG emissions and thereby in reaching the climate goal to limit global warming.

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Appendix A

Table A1. Greenhouse gas emissions related to agriculture covered by the CAPRI model

Source	Greenhouse gas type
Agricultural emissions	
Enteric fermentation	Methane
Manure management (housing and storage)	Methane
Manure application on soils except pastures	Nitrous oxide
Manure deposition on pastures	Nitrous oxide
Inorganic fertiliser application	Nitrous oxide
Crop residues	Nitrous oxide
Indirect from ammonia volatilisation	Nitrous oxide
Indirect from leaching and runoff	Nitrous oxide
Cultivation of organic soils	Nitrous oxide
Rice cultivation	Methane

Table A2: Impact removal of voluntary coupled support (VCS) on agricultural greenhouse gas emissions for selected countries

	Change, kt CO_2-eq	Change, %
World	**-480**	**-0.01**
European Union	*-1764*	*-0.4*
‘France	-972	-1.4
Spain	-267	-0.8
Poland	-159	-0.5
Sweden	-101	-1.5
England	+224	+0.5
Ireland	+126	+0.6
Germany	+53	+0.1
Non-European Union	*+1284*	*0.0*
Brazil	+269	0.1
Argentina	+144	0.1
India	+124	0.0
Russia	+96	0.1
Australia and New Zealand	+82	0.1
USA	+66	0.0

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