Impact of Border Carbon Adjustments on Agricultural Emissions – Can Tariffs Reduce Carbon Leakage?

Ida Nordin, Frederik Wilhelmsson, Torbjörn Jansson, Thomas Fellmann, Jesús Barreiro-Hurle, Mihaly Himics

Selected paper prepared for presentation at the 2019 Summer Symposium: Trading for Good – Agricultural Trade in the Context of Climate Change Adaptation and Mitigation: Synergies, Obstacles and Possible Solutions, co-organized by the International Agricultural Trade Research Consortium (IATRC) and the European Commission Joint Research Center (EU-JRC), June 23-25, 2019 in Seville, Spain.

Impact of Border Carbon Adjustments on Agricultural Emissions – Can Tariffs Reduce Carbon Leakage?

**Ida Nordin*, Fredrik Wilhelmsson†, Torbjörn Jansson*,
Thomas Fellmann‡, Jesús Barreiro-Hurle‡, Mihaly Himics‡**

* Department of Economics and AgriFood Economics Centre,
Swedish University of Agricultural Sciences
† AgriFood Economics Centre, Lund University
‡ European Commission, Joint Research Centre Seville
Corresponding author: Ida Nordin, ida.nordin@slu.se

Disclaimer: The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

Abstract

There is concern that unilateral climate action in the EU agricultural sector may cause higher emissions abroad (i.e. emission leakage) and harm the competitiveness of the EU´s agricultural sector. Applying the CAPRI model, this paper assesses the potential for border carbon adjustments (BCA) in the form of import tariffs to limit the leakage of emissions and preserve the competitiveness of the EU agricultural sector. Our results show that even though BCA reduces emission leakage, 92 % of the emission reduction in the EU is still offset by emission increases outside the EU. What limits the effectiveness of the investigated BCA measures is that those measures are unilateral, and thus they only adjust for the reduced competiveness at the EU internal market, whereas EU exports are still largely replaced by commodities produced in less GHG-efficient countries. Therefore, BCA alone cannot solve the high risk of emission leakage in the agri-food sector as a consequence of unilateral EU climate action.

1 Introduction

To curb climate change many countries have implemented unilateral measures to reduce greenhouse gas (GHG) emissions. However, domestic emissions reduction from unilateral policies can lead to a re-allocation of production to countries with less stringent or no mitigation targets, resulting in emission increases in these countries, i.e. emission leakage. From a global perspective, emission leakage undermines mitigation efforts (Perez Domínguez and Fellmann 2015) and may even result in a net increase in global emissions (Babiker 2005). Accordingly, unilateral climate policies may raise concerns of harming the local economy while at the same time not efficiently reducing global emissions (Elliott et al. 2010). For example, empirical studies on the impact of the Kyoto protocol, where ratifying developed countries agreed to reduce GHG missions, found evidence that the implemented commitments causes carbon leakage (Martin et al. 2014, Aichele and Felbermayr 2015, Larch and Wanner 2017). Although the Paris Agreement brings almost all nations into the common cause to undertake ambitious efforts to combat climate change, it is up to each participating country to decide on its mitigation targets, which mitigation policies they implement and which sectors they include. Due to this heterogeneity in the domestic action, the concerns of loss in competitiveness and emission leakage maintain.

Concerns about emission leakage and competitiveness have led to special treatment or complete exemption of emission-intensive trade-exposed sectors from carbon pricing (Juergens, Barreiro-Hurlé, and Vasa 2013). In the European Union (EU), for example, certain sectors like agriculture and transport are not included in the emission trading system (EU-ETS), and some sectors that are covered by the EU-ETS but considered to be exposed to a high risk of leakage received emission allowances for free (European commision 2014, European Parliament and the Council 2018).

In this context, the agricultural sector is of particular interest as it is both a significant source of non-CO_2 GHG emissions, causing about 10 – 12 % of global GHG emissions (excl. land use, land use change and forestry) (Smith et al. 2014) and significantly trade-exposed. Moreover, the agricultural sector provides a largely unused potential to reduce GHG emissions (Grosjean et al. 2016).

Emissions from agriculture are included in most of the (Intended) Nationally Determined Contributions, (I)NDCs, committed by the countries to the UNFCCC. While agriculture is included in the economy-wide contributions, however, only few countries set sector-specific quantitative targets for agriculture in their (I)NDCs (Richards, Wollenberg, and van Vuuren 2018). In the EU, agriculture and some other sectors not included in the EU-ETS are covered by the Effort Sharing Decision (ESD), which aims at a 10 % reduction of GHG emissions of the included sectors by 2020 compared to 2005 (European Commission 2016). The latest EU legislative proposal for the implementation of the Paris Agreement further strengthens the ESD target for the period after 2020, aiming at a 30 % reduction by 2030 compared to 2005. The overall ESD emission reduction target is distributed between EU member states according to non-uniform GHG mitigation targets based on the relative gross domestic product (GDP) per capita, with large variation across member states with a minimum of no reduction for Bulgaria and a maximum of 40 % reduction for Luxembourg and Sweden (European Parliament and the Council 2018). These reduction targets are, however, specific to member states and not individual sectors, i.e. no explicit policy measures have been implemented that would force EU member states to reduce their GHG emissions from agriculture (European Parliament and the Council 2018).

The use of country specific targets and differentiated policy for the non-ETS sectors might lead to sub-optimal mitigation efforts, as low cost opportunities to reduce emissions may be unused in some member states and sectors, while others will implement reduction measures with a relatively high cost (De Cara and Jayet 2011). In addition, the impact on global emissions, i.e. the relevant target to combat climate change, is not assured to be positive as emission leakage might largely offset the domestic emission reduction efforts in agriculture (Perez Dominguez et al. 2012).

Several studies point out that achieving the goal of the Paris Agreement to limit the temperature increase to well below 2 degrees Celsius by the end of the century requires the contribution of agriculture to the GHG emission reduction efforts (Wollenberg et al. 2016, Rogelj et al. 2018). Accordingly, a cost effective solution for the inclusion of agriculture in global GHG emission mitigation has to be found. Such a solution should counteract emission leakage and alleviate competitiveness losses. One policy option to counteract emission leakage are import tariffs based on the carbon content of imports, so-called border carbon adjustments (BCA). BCA are intended to level the playing field between producers in carbon taxing countries and in non-carbon taxing countries, and in times of uneven climate action BCA are a policy option that is gaining growing political interest (Mehling et al. 2018).

In this paper we simulate the impact of pricing domestic non-CO_2 GHG emissions in the EU agricultural sector alone or combined with BCA to assess the potential impacts on GHG emission mitigation, carbon leakage and competitiveness as well as associated side effects of BCA. The paper adds to the existing literature on BCA assessing their performance in the agricultural sector and provides insights to the impact of unilateral climate policy for the EU agricultural sector.

2 Background border carbon adjustments

BCA are intended to alleviate emission leakage and the negative impacts on international competitiveness for business sectors arising from uneven climate efforts between countries. BCA measures typically come in the form of import tariffs, export rebates, or an obligation for importers to surrender domestic carbon allowances for the amount of CO_2 that is emitted as a consequence of the good's production or a combination thereof (Kuik and Hofkes 2010).[1] Although BCA measures exist in different forms, the political debate around BCA mostly focuses on imports tariffs (taxes), in combination with the introduction of carbon pricing for domestically produced goods. That corresponds to a strategy of charging an import tax that is equivalent to the carbon tax liability of domestically produced goods.

Since BCA policies might become in conflict with the World Trade Organization (WTO) principle of treating imported and locally-produced goods equally, other WTO partners may challenge BCA policies and may put in place retaliation measures. In the case of the EU, Fouré, Guimbard, and Monjon (2015) suggest that such retaliation is likely to target products sensitive to the EU, traditionally including agricultural and food commodities. Still, the WTO-principle on national treatment actually allows for BCA policies, assuming that trade neutrality of the domestic taxation is ensured. BCA might also be justified on the ground of environmental concerns (Odell 2018, Di Leva and Xiaoxin 2017, Mehling et al. 2017). Regarding the specific BCA measures, Böhringer, Fischer, and Rosendahl (2014) note that export rebates may be inadmissible under the WTO rules, thus designing BCA with a focus on import tariffs possibly increases its compatibility with WTO rules.

The practical implementation of BCA measures needs to address the following issues:

i) Defining the adjustment base and the calculation rules of the related indicators, e.g. calculation of carbon content of goods;
ii) Decision on applying a flat rate- or exporter-specific (differentiated by origin) adjustment;
iii) The selected range of measures, possibly including import tariffs, emission allowances and export refunds

[1] For a comparison of a tax-based BCA and an allowance-based BCA, see Monjon and Quirion (2011).

iv) Defining the policy parameters of the BCA measures, e.g. the exact import tariff rates on imported goods

To guarantee that importers are not discriminated compared to domestic producers the carbon content of goods could be calculated based on best available technology (BAT). The use of BAT to calculate carbon content is likely to make the BCA measures admissible under WTO rules (Ismer and Neuhoff 2007). A viable option to determine BAT could be, as suggested by Monjon and Quirion (2011), to use product-specific benchmarks as, for example, used in the EU ETS to determine the per unit level of free allowances issued to sectors deemed at risk of carbon leakage. A similar approach could be applied to the agricultural sector, calculating embodied carbon in imports based on product specific emission levels for the EU. This way of determining emissions implies a uniform tariff or allowance cost for all exporting countries independent of the actual emission levels in the exporting country. A differentiated emission base or tariff would benefit exporters from countries with emission efficient production technologies but would not be in line with the national treatment principle. However, it might be possible to motivate this differentiation due to environmental concerns (GATT Article XX).

Once carbon content has been determined a specific tariff based could be levied on the products carbon emissions (tariff-based system) or importers could be obliged to buy carbon allowances in the EU equalling the carbon content of imported goods (allowance-based system). To adhere to the national treatment principle, an allowance-based system is simpler than a tariff-based system as in the latter it would be difficult to determine the level of the tariff that results in similar treatment of domestic and imported goods (Monjon and Quirion 2011). However, in practice BCA based on actual emissions seems to be infeasible because of high transaction costs due to information requirements, moreover its compatibility with the WTO rules is still disputed (Holzer 2016, Fouré, Guimbard, and Monjon 2015).

BCA have the potential to perform better in terms of leakage prevention and abatement than other options (Ward, et al., 2015). The notion that BCA may be more efficient than output-based rebating is supported in several studies (Böhringer, et al., 2014, Fischer and Fox, 2012, Monjon and Quirion, 2011). The capacity to reduce leakage of BCA has been assessed in a series of papers, which we will briefly outline below.

Based on a review of 25 studies, Branger and Quirion (2014) conclude that BCA can reduce leakage ratio by 6 percentage points, keeping other parameters constant. Carbon leakage ranges from 5 % to 25 % without BCA and from 5 % to 15 % with BCA. Furthermore, leakage decreases with the size of the coalition implementing carbon taxes, and that BCA covering all sectors and being combined with export rebates minimize the carbon leakage.

Similarly Elliott et al. (2010) found that BCA would be effective in terms of reducing carbon leakage resulting from a carbon tax in in Kyoto Annex B countries. Fouré, Guimbard, and Monjon (2015) use a version of the MIRAGE model to analyse the effects of BCA with the assumption that the BCA targets European imports of energy intensive trade exposed goods, independent of their origin. They model BCA as an obligation for importers to surrender a quantity of allowances corresponding to direct CO_2 emissions generated during the production of the imported good, whereas other authors, like e.g. (Böhringer, Balistreri, and Rutherford 2012), have chosen to model the BCA as border carbon tariff.

Based on quantitative experiments Böhringer, Carbone, and Rutherford (2018) conclude that carbon tariffs applied to the full carbon content of imported goods are effective in reducing carbon leakage from unilateral OECD policies. But applying the domestic carbon tax rate on the full carbon footprint of imports would result in higher than optimal tariffs because incentives for exporting countries to re-direct export to countries without carbon tariffs reduce the optimal tariff.

Böhringer, Fischer, and Rosendahl (2014), assessing policies to reduce leakage with unilateral climate policy, conclude that in terms of costs, countries with climate policy would prefer carbon import tariffs to full border adjustment or output-based rebates, and that the gains of full border adjustment (including export rebates) are small compared to import tariffs only.

Simulations of Elliott et al. (2013) demonstrate that simplified border taxes that do not create incentives for foreign producers to use cleaner production technologies may perform significantly worse than perfect border taxes in reducing leakage.

While the literature on BCA outlined above indicate the capacity of BCA to reduce leakage and refer to specific difficulties on the BCA design, to the best of our knowledge there has been no assessment of the performance of BCA in the agricultural sector.

3 Methodology and scenario assumptions

Methodological framework

For the policy simulations we use the CAPRI (Common Agricultural Policy Regional Impact Analysis) modelling system (Britz and Witzke 2014). CAPRI is an economic comparative-static partial equilibrium model focusing on agriculture and the primary processing sectors. CAPRI consists of two interacting modules, linking a set of mathematical programming models of EU regional agricultural supply to a spatial multi-commodity model for global agri-food markets. A positive mathematical programming (PMP) approach is used in the regional supply models to simulate the profit maximizing behaviour of representative farms for all EU regions, taking constraints of land availability, nutrient balances for cropping and animal activities and policy restrictions into account. The market module consists of a spatial, non-stochastic global multi-commodity model for about 60 primary and processed agricultural products, covering 77 countries in 40 trading blocks. Bilateral trade flows and attached prices are modelled based on the Armington assumption, i.e. differentiating imports by place of origin, and consumer preferences are for imports are calibrated to a benchmark dataset. The behavioural functions for supply, feed, processing and human consumption in the market module represent supply and demand for primary agricultural and processed commodities (M'barek et al. 2017, Britz and Witzke 2014).

The CAPRI version used in the paper only considers non-CO_2 emissions (methane and nitrous oxide) directly related to the UNFCCC common reporting category 'agriculture'; CO_2 emissions and removals of other categories, like for example, from Land Use, Land Use Change (LULUCF), are not included. For the EU, the calculations of non-CO_2 emissions are based on the input and output of production activities in CAPRI, following IPCC guidelines (IPCC 2006). A detailed description of the general calculation of agricultural emissions in CAPRI is given in Leip et al. (2010), Perez Dominguez et al. (2012), Van Doorslaer et al. (2015), Pérez Domínguez et al. (2016) and Fellmann et al. (2018). GHG emissions for the rest of the world are calculated on a commodity basis (i.e. per kg of product) in the market model. The emission intensities in non-EU countries are estimated based on historic emissions and production data from FAOSTAT. To allow for changes in emission efficency over time, e.g. due to technology improvement, trend functions are estimated for the emission intensities in the rest of the world using IPCC Tier 1 coefficients within a Bayesian estimation framework that combines production quantities and emission inventories from FAOSTAT (Himics et al. 2018). For more information on the approach see Jansson, Pérez Domínguez, and Weiss (2010) and Perez Dominguez et al. (2016).

Scenario assumptions

The analysis covers three main scenarios including the business as usual reference scenario. To assess the impact of BCA we first introduce a carbon tax for agricultural commodities produced in the EU based on their emission intensity. In the second policy scenario, BCA tariffs on imported commodities are added in addition to the EU carbon tax. Export rebates would be another possible BCA measure, but we discarded it as export rebates may work as a kind of export subsidy and therefore less feasible under WTO rules. The target year for all scenarios is 2030, and the major scenario assumptions can be summarised as follows:

i) *Reference scenario (REF):* The reference scenario considers agricultural, environmental and trade policies as ratified by 2016. The REF is calibrated to the European Commission's outlook for agricultural markets and income (European Commission, 2016), which itself is based on the OECD-FAO (2016) agricultural market outlook, providing medium-term projections in a consistent international framework by using also external sources for the assumptions on macroeconomic developments (like, for example, GDP growth, exchange rates, world oil prices, and population growth).

ii) *Scenario Tax:* This scenario is based on REF, but in addition the EU introduces a production based carbon tax of 120[2] EUR/t CO_2 equivalent on all agricultural commodities sold from EU farms. The tax is based on actual average emission intensities per product in each country. The tax is applied at farm gate, which means that it is also applied to tradable feed such as feed cereals, and that the emission factors for animals used to base the tax on, excludes the implicit content of tradable feed (the feed is taxed when it is produced by the farm) but the final meat product includes them.

iii) *Scenario Tax & Tariff:* This scenario adds to the Tax scenario a BCA in form of a tariff of 120 EUR/t CO_2 equivalent based on the country or region specific emission intensity of the imported commodities. This BCA is applied both to primary production and processed goods to cover all trade. In order to make the BCA tariff rate comparable with the carbon tax rate inside the EU, it is based on emission intensities that also reflect the content of tradable inputs such as animal feed. If that were not the case, imports of e.g. beef with a large content of tradable feed would be at an advantage compared to EU production or to imports of beef based on non-tradable feed such as grazing. Similarly, processed products such as vegetable oils have tariffs based on the oilseed content.

   The BCA is implemented on top of existing tariffs. In particular:

   a. The MFN-rates of the EU were increased by the BCA.
   b. All free trade agreements were replaced with special import "quotas" where an unlimited quantity can be imported to the EU at a tariff corresponding to the BCA.
   c. All existing tariff rate quotas (TRQ) were "shifted upwards", i.e. the BCA was added both to the in- and out-of-quota rates.

The emission intensities that the taxes and the tariffs are based on are heterogeneous across products and origin. In general, the product with the highest emission intensity is beef, whereas crops have much lower emissions intensities, and accordingly taxes are higher for meat than for crops.

In addition to the two main policy scenarios we also provide a sensitivity analysis to further decompose the impacts of the different parameters driving the results. Therefore we run variants of the policy scenarios, with other combinations of emission factors and tax rates. For these auxiliary scenarios only selected results are reported in this paper. Table 1 lists the scenarios and their key mitigation policy assumptions.

[2] The carbon price was chosen to equal the Swedish CO_2 tax on fossil fuels of 120 Euro per tonne CO_2 eq (in 2018 years price level).

Table 1: Scenario details

Scenario code	EU carbon tax	BCA tariff on EU imports	Tax level (EUR/t CO_2eq)	Other
REF	None	None	0	
Tax	Different per MS*	None	120	
Tax & Tariff	Different per MS*	Different per exporting region***	120	
Complementary scenarios for the sensitivity analysis				
TAXFLAT_BCANO_120	Same in all MS**	None	120	
TAXFLAT_BCAFLAT_120	Same in all MS**	Same for all exporters****	120	
TAXNO_BCAREG_120	None	Different per exporting region***	120	
TAXREG_BCANO_30	Different per MS*	None	30	
TAXREG_BCAREG_30	Different per MS*	Different per exporting region***	30	
TAXREG_BCANO_120 _EMIS	Different per MS*	None	120	Emission intensity*****
TAXREG_BCAREG_120_EMIS	Different per MS*	Different per exporting region***	120	Emission intensity*****

* Carbon tax for each EU member state (MS) based on average agricultural emissions computed in the reference scenario
** Production emission taxes based on fixed emission coefficients per product that are the same everywhere in the EU
*** Carbon tax rate based on emissions per commodity computed for each region in the world
**** Carbon tax rate identical for all countries exporting to the EU, based on the average EU emission coefficients
***** Emission intensity (tonne CO_2eq/tonne) for beef in India half of reference value.

4 Results

The introduction of a carbon tax on agricultural products in the EU leads to a decrease in EU production of emission-intensive products such as beef and milk, resulting in a reduction of EU non-CO_2 GHG emissions. The EU emission decrease is counteracted by emission increases in the rest of the world, i.e. emission leakage, which leads to a net increase in total global emissions. An import tariff as BCA reduces the leakage of emissions, but still emission leakage is large. The following results focus on the main scenarios, but the auxiliary scenarios are discussed in a sensitivity analysis. If not explicitly stated otherwise, all changes referred to are the changes compared to the reference scenario in 2030.

Agricultural non CO_2 GHG emissions

The scenario Tax, with a carbon tax of 120 EUR/t CO_2 equivalent on all agricultural commodities sold from EU farms, leads to a decrease of EU agricultural non-CO_2 emissions by 7.6%, i.e. 33.7 million tonnes (Mt) (Figure 1). However, there is large leakage of emissions to the rest of the world which leads to a net increase of agricultural emissions in the world by 3.6 Mt (equivalent to 0.8% increase in EU emissions). Accordingly, the emission leakage effect is 111%[3]. The scenario Tax & Tariff, with both a tax and an import tariff, does contribute to decreasing emission leakage. With the tariff emissions in the EU decrease less than with only the domestic carbon tax, and at the same time emissions outside the EU increase less, the net effect being a decrease in global emissions, but only by 2.3 Mt. While emissions in the EU decrease by 28.4 Mt compared to the reference, outside the EU the emissions increase by 26.1 Mt. Thus, emission leakage is 92 % of the emission decrease in the EU. Accordingly, the tariff achieves its goals to some (very limited) extent, but still only results in total global emissions that are close to the reference scenario emissions (equivalent to 0.5% decrease in EU emissions).

[3] Leakage in percentage terms is calculated as emissions increase outside the EU/emission decrease in the EU

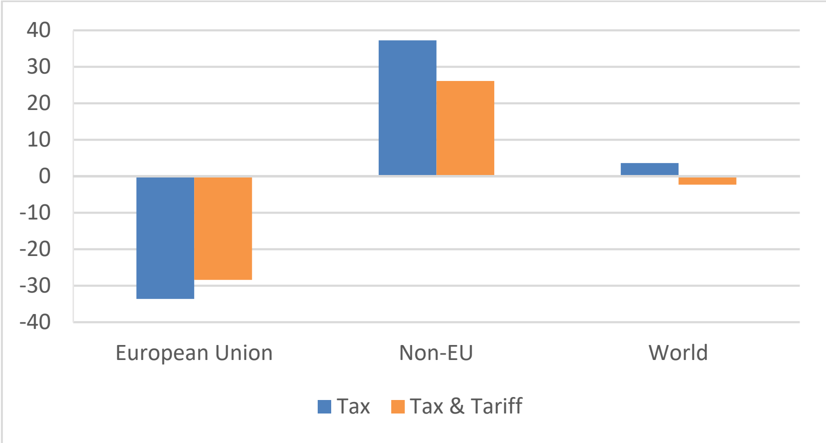


Figure 1 Change in agricultural non-CO_2 GHG emissions (Mt CO_2eq.) by 2030

The large emission leakage can be explained by the possibilities for trade and the differences in emission intensities across products and regions. Figure 2 splits the changes in emissions among sectors, in EU and Non-EU respectively. The emission decrease in the EU in the Tax scenario is mainly due to a decrease in beef and milk production and the related emission decline. Both sectors contribute with emission decreases of 12.9 and 12.3 Mt, respectively. As these sectors have high emission intensities the absolute tax level is higher, which provokes a decrease in production as long as the tax burden is higher than the revenue achieved by keeping the production activity. Crops, pork and poultry have lower emission intensities and are less affected by the tax with smaller related production decreases. Following the production changes in the EU, the increase of emissions outside the EU is mostly due to an increase in production of beef and the related emissions, which accounts for 29.3 Mt or 79% of the total emissions increase outside the EU. There is almost no leakage of emissions from milk production while to some extent from sheep and goat meat. With the introduction of the tariff the decline in emissions in the EU is reduced, and the differences between scenarios are similar across sectors. Outside the EU the emissions are also smaller in the Tax & Tariff scenario than in the Tax scenario. This is, however, only to a smaller part due to a decrease in emissions from beef, but to a large part due to a decrease in emissions from sheep and goat meat – other products with high emission intensities.

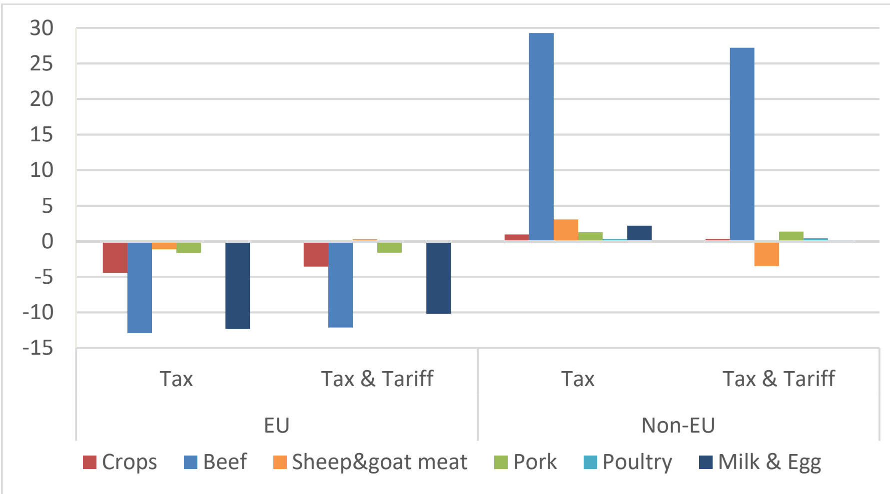


Figure 2 Change in non-CO_2 GHG emissions by sector (Mt CO_2eq.) by 2030

Trade

The introduction of the emission tax leads to import and export changes in the EU. Figure 4 shows that in the Tax scenario, EU export quantities decrease for most products, in particular for beef (-51%) and sheep and goat meat (-58%). Conversely, imports increase for all livestock products (Figure 4), most importantly (in relative terms) for pork (45%) and sheep and goat meat (35%). In the Tax & Tariff scenario, the BCA tariff leads to decreasing EU imports, especially for beef and sheep and goat meat (-90%). These decreases in imports are a direct consequence of the tariff. Moreover, as less commodities are imported, the EU exports even less than in the Tax scenario, in order to (partially) satisfy domestic consumption. This latter effect is possible as the domestic carbon tax is lower than the tariff for imports from many countries. The tax and the tariff changes the trade of especially beef, while not so much for dairy, which can explain the low emission leakage of the dairy sector.

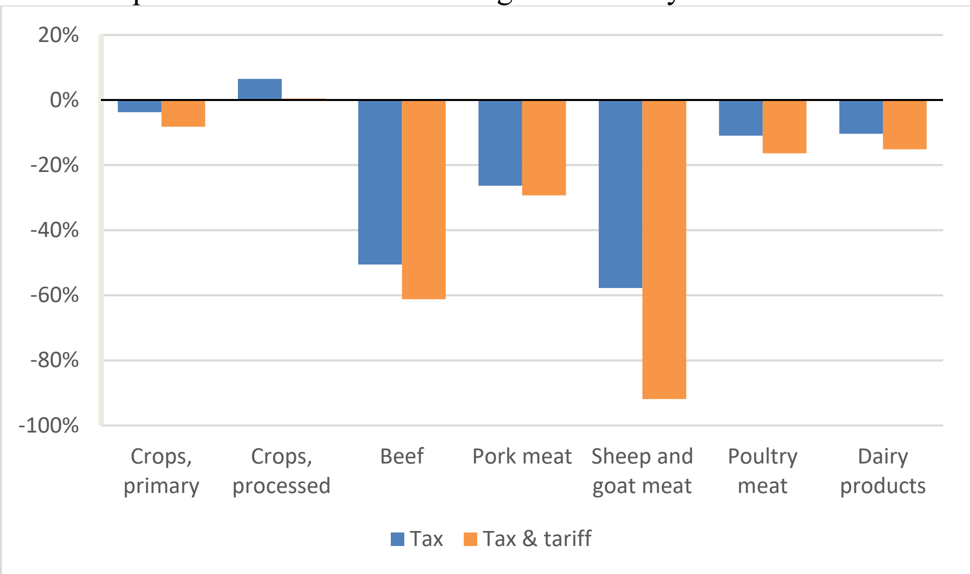


Figure 3 Changes in EU exports by 2030

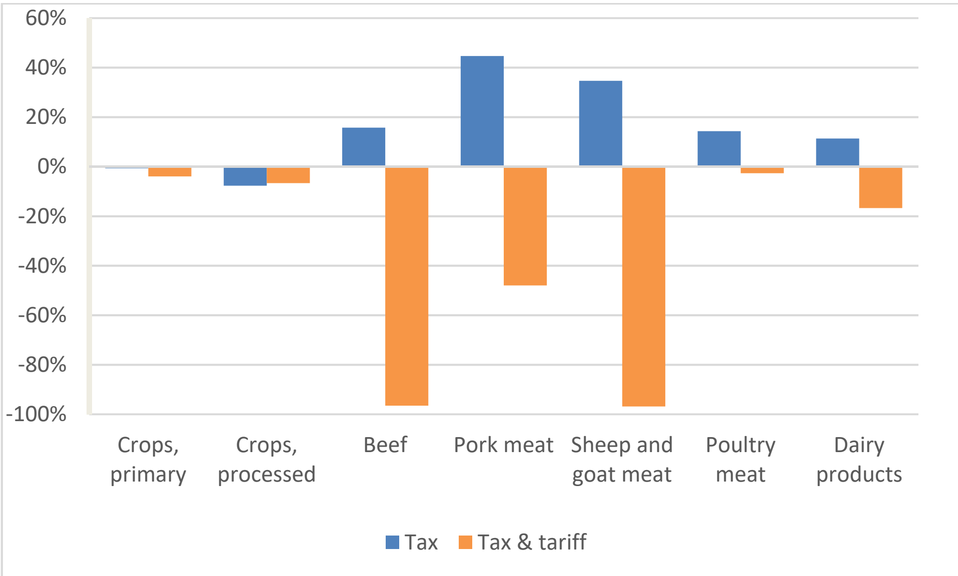


Figure 4 Changes in EU imports by 2030

As the largest impacts are found for beef we further investigate the dynamics behind the results. In the Tax scenario, global beef production decreases by almost 236 Mt, whereas the decrease in the EU is 933 Mt (Figure 5, left-hand side). This means 75% of the EU production decrease is compensated by production increases in non-EU countries. In the Tax & Tariff scenario global beef production decreases by 231 Mt (i.e. in this scenario 73% of the EU production decrease is compensated). Thus beef production decreases in both scenarios, which would have the potential to decrease global emissions, but emissions from beef increase in both scenarios, with the BCA tariff having only a marginal effect on both global production and emissions from beef. The large emission increase and low efficiency of the tariff can be tracked to the changes in EU trade (right-hand side of Figure 5). EU exports decrease in both scenarios, adjusting for the domestic production decrease, and in the Tax & Tariff scenario also for the import decrease. It has to be highlighted that the tariff even leads to decreases in EU beef imports compared to the reference scenario.

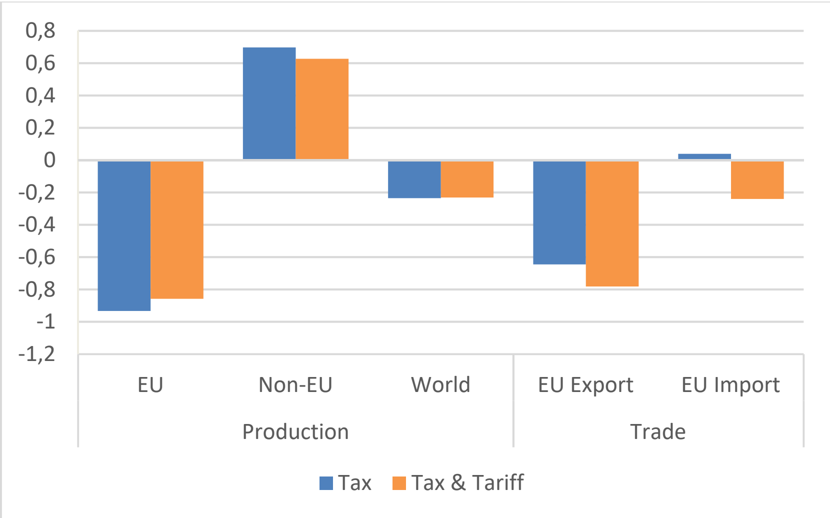


Figure 5 Changes beef production and trade (Mt) by 2030

The effects of the decrease in EU beef exports are important for our analysis. This causes a relatively large reallocation of beef production from EU to other regions that fill the export gaps. The trade changes are not homogenous across trading partners, as illustrated for changes in domestic production, net trade with the EU and with other Non-EU regions with some of the non-EU regions with largest trade changes (Figure 6), with changes. In the Tax scenario, these regions increase their production as they export more to or import less from the EU, and export more to non-EU regions. When the tariff is introduced, some of these regions increase their beef production less than in the Tax scenario, hence emitting less than with only the tax. The regions showing less emission increases in the Tax & Tariff scenario are those regions that trade with the EU, such as Brazil. Brazil increases production in the Tax scenario, and also net trade with EU (export to EU) and non-EU regions (filling EU export gaps). In the Tax & Tariff scenario, Brazil's net trade to EU decreases, but trade to other regions increases, as Brazil is filling the increased EU export gaps. In total, Brazil's beef production increases less than in the Tax scenario. For Russia, production increases, imports from EU decrease, and the remaining gap is filled by imports from other regions, e.g. Brazil. These effects in Russia are more pronounced in the Tax & Tariff scenario as the EU decreases its exports. For African LDC, net trade to non-EU regions is small and there are no large changes with the scenarios. In the Tax scenario imports from the EU decreases, and in the Tax & Tariff scenario the import is even smaller when EU exports decrease. Thus the production increase. In India, production also increases in both scenarios, as India increases its exports to non-EU regions, an effect that is more pronounced in the Tax & Tariff scenario. As there are no beef trade flows with the EU an export flow to the EU cannot be targeted with the tariff.

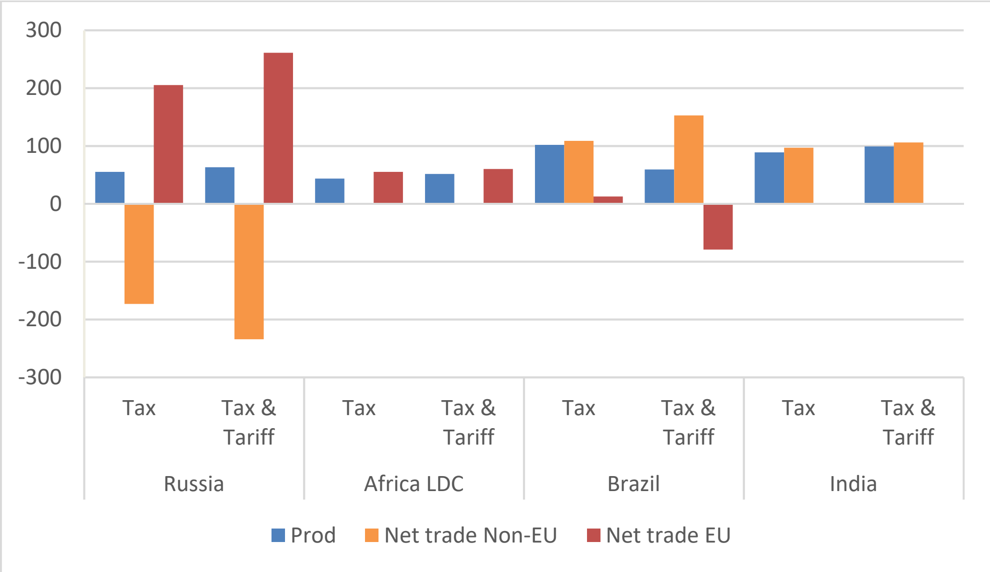
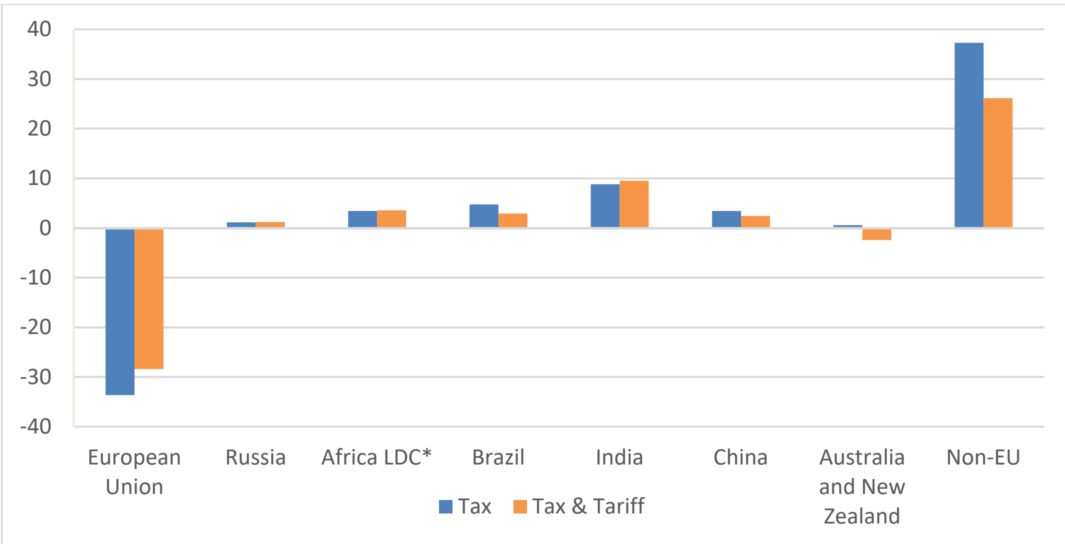


Figure 6 Changing trade flows: Beef production and net trade changes for most relevant countries

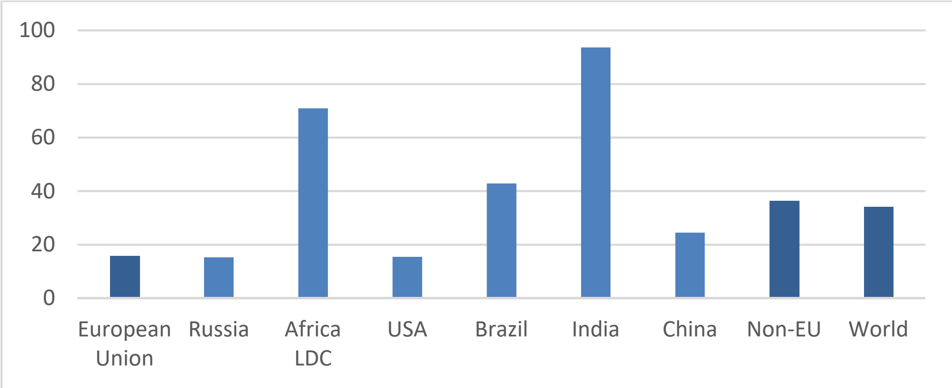
Geographically, the largest part of the increase in emissions occurs in India, Brazil, China, Africa (mainly LDCs) and Russia. Figure 7 shows the regions responsible for the largest emission increases in non-EU countries, but emissions increase in basically all non-EU regions. Most of the emission increases are related to increased beef production, especially in African LDCs, India, and Brazil. An exception is Australia and New Zeeland, where there is a large emission decrease caused by changes sheep and goat meat production in the Tax &Tariff scenario.

The trade changes alone cannot explain the emission leakage, but the emission intensities in regions to which production is reallocated are important. Figure 8 shows the CAPRI model emission intensities, for beef in selected countries. For example, India has around five times higher emission intensity than the EU. The fact that many of these regions have higher emission intensities makes their increases in production result in large emission increases. In the Tax & Tariff scenario the beef production even increases relative to the Tax scenario in some non-EU countries like African LDCs and India, and hence the related emissions are higher.



*Africa LDC = aggregate of least developed countries in Africa

Figure 7 Global changes in agricultural non-CO_2 emissions (Mt CO_2eq) - largest contributors



*Africa LDC = aggregate of least developed countries in Africa

Figure 8 Emission intensities for beef (tonne CO_2eq./tonne beef)

EU production

Figure 9 shows changes in production for aggregated groups of primary products in the EU in both scenarios. In the Tax scenario, production decreases for all sectors. The production decrease is most pronounced for EU beef (-10.2%), sheep and goat meat (-9.7%) and crops (-5.8%). The EU production decrease is somewhat smaller in the Tax & Tariff scenario, but the difference is below one percentage point for most commodities. The exception is sheep and goat meat, where the large decrease in EU production in the Tax scenario almost goes back to the reference scenario values with the tariff. There are also differences within the crop aggregate, where sugar, cereals, and to some extent oilseeds decrease most in the Tax scenario. In the Tax & Tariff scenario the change in oilseeds production disappears. The production decreases are primarily a direct consequence of the domestic carbon tax, but there is also a secondary effect due to decreased demand for crops used as feed.

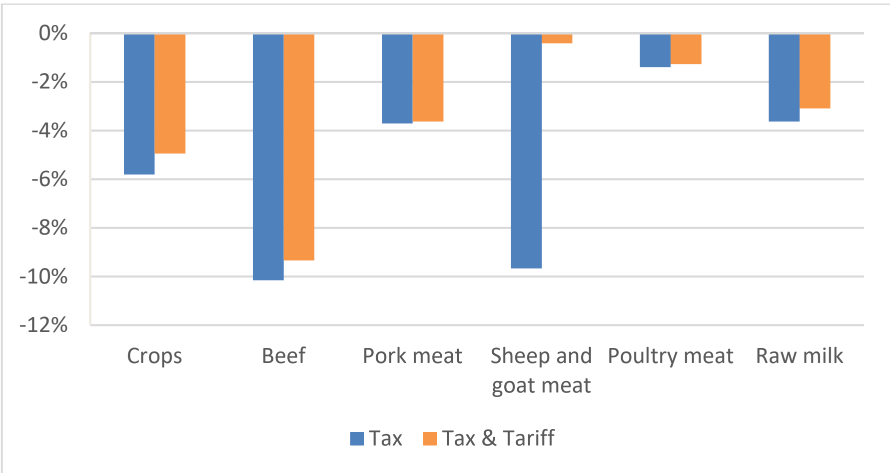


Figure 9 EU production changes by 2030, %

Sensitivity analysis

The results of the two main policy scenarios are based on specific assumptions on how the EU carbon tax and tariff are implemented, i.e. differentiated per EU member state (MS) and per exporting world region. To assess the impacts of different assumptions regarding some parameters of the policy implementation we conduct a sensitivity analysis with varied assumptions on the EU carbon tax (tax levels of 120 and 30 EUR/t CO_2eq, differentiated and non-differentiated per MS) and the application of a tariff (with/without, differentiated and non-differentiated per exporting region). Moreover, as emissions from India showed a large impact on the results of the two main policy scenarios, we also conduct two additional scenarios in which we assume an emission intensity of Indian beef that is half of the reference value (see Table 1 for the scenario overview). The results on emission changes for these additional scenarios are displayed in Figure 10.

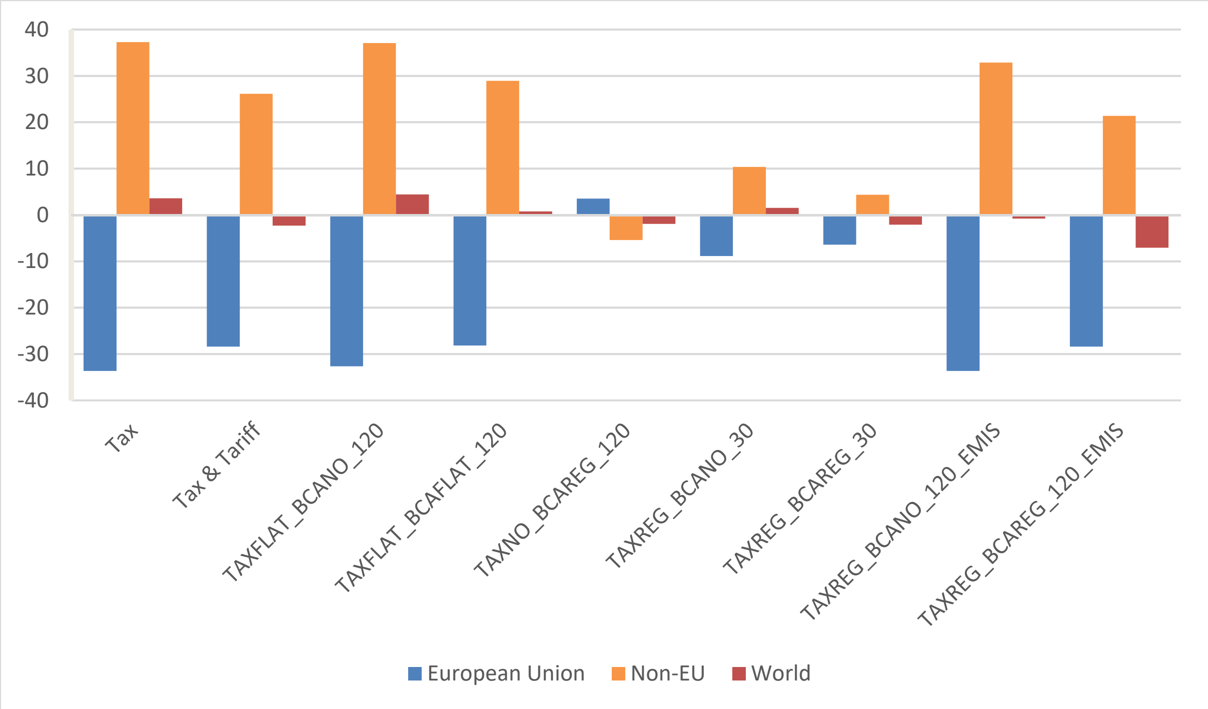


Figure 10 Changes in agricultural non-CO_2 GHG emissions (Mt CO2eq) by 2030 - all scenarios

Comparing our main scenarios that have a regionally differentiated tax and tariff with the scenario where the tax and the tariff rate is instead equal to the EU average (TAXFLAT_BCANO_120, TAXFLAT_BCAFLAT_120), only small differences in emissions can be seen. When the tax rate is flat across the EU rather than regionally differentiated EU emissions decrease slightly less, and total global emissions are slightly larger. This effect is due to less emission decreases in some regions with high emission intensity among the EU regions. A flat rate for the tariff also leads to only small emission increases, which can mainly be explained by additional emissions from trade in third countries. Thus the differentiated is more emission efficient, but the difference in terms of total emissions does not seem crucial.

To see the isolated effect of the tariff we analyse a scenario with only the tariff and no domestic EU carbon tax. Here emissions increase in the EU as EU production has a relative advantage compared to non-EU production. As EU imports decrease and also related non EU emissions, the net effect is a decrease in total global emission of 1.9 Mt CO_2 eq., i.e. which is almost the same as in the Tax & Tariff scenario.

In the EU ETS system the carbon price is currently around 30 Euros per tonne CO_2 eq., and we use this price level to look at the sensitivity of the results to different carbon prices. The production decrease in the EU is much smaller than with the higher tax rate. Accordingly, the EU emission decrease is smaller and also the emission increase in the rest of the world is rather small. The net effect is an increase in total global emissions of 1.5 Mt CO_2 eq., which is less than half of the increase with the 120 Euro carbon tax. When the tariff is introduced in addition to the 30 Euro/t CO_2eq carbon price in the EU, the global emission decrease is 2.1 Mt CO_2 eq., which is similar to the decrease in the Tax & Tariff scenario with the higher carbon price. Thus the lower carbon price in the EU seems to be almost equally effective in terms of global emission reduction as the higher carbon price. This is mainly due to the aforementioned relatively high emission efficiency in EU production compared to non-EU production. As emission intensities (tonnes CO_2eq./tonne product) are generally lower in the EU than in most non-EU countries, substituting EU production decreases with non-EU production (partially) offsets the emission reductions achieved in the EU. Moreover, as the producer price increase in the EU is higher in the scenario with the 120 Euro EU carbon tax (triggered by the bigger EU production decline) compared to the scenario with the 30 Euro carbon tax, there is still enough incentive for non-EU producers to pay the higher tariff in order to export to the EU. As consumer price elasticities are rather low in the EU, these results show that it is difficult to reach a large decrease in (global) emissions with the modelled measures as long as EU consumers do not significantly change their consumption habits

The two main policy scenarios showed India as a large contributor to the emission increase outside the EU, which is mainly due the country´s high emission intensity for beef. Therefore we look at the impact of assuming a lower emission intensity (half) in India. There is an uncertainty in the level of emission intensities in general, and India in particular has a special beef production, where many cows are not slaughtered due to cultural norms, but there is also a specific beef producing sector. This means that the extra beef actually produced could have lower emission intensity than the average. We find that with this assumption total global emissions in the Tax scenario would decrease by 0.8 Mt CO_2 eq., and with the tariff emissions would decrease by 7.1 Mt CO_2 eq. globally. The change in assumptions on the emission intensity is quite large, but shows that these intensities matter. Moreover, the specific trade flows affected have a large impact on results. This shows the importance of having detailed information on emissions. Here we focus on lower intensity, but we can also suspect that other regions produce beef with higher emission intensity on the margin.

5 Discussion and conclusions

Our results show that a unilateral carbon tax in the agricultural sector in the EU causes substantial emission leakage which is only offset to a limited extent with the introduction of BCA. The carbon tax induces a reduction of production in the EU which results in increased production outside the EU and increased trade between non-EU countries. Accordingly, the production reduction in the EU provokes three main responses in non-EU countries: (i) increased exports to the EU where production costs are increased by the carbon tax, (ii) increased exports between other non-EU countries as exports from the EU decline, and (iii) increased production for the domestic market in non-EU countries to substitute the more expensive imports from the EU. Thus, conclusions regarding the efficiency of BCA based on models not considering multiple agents and trade displacement (Hecht and Peters 2019) might be too optimistic. The modelled BCA measures mainly affect imports to the EU, which decrease due to higher import prices. However, the impact on non-EU trade and non-EU markets is limited, which leads to a relative ineffectiveness of the EU BCA tariff in terms of global GHG emission abatement.

Besides the impact of changes in quantities produced, emissions are affected by the location of production as emission intensities vary significantly across countries. Thus, in addition to the general emission effect of increased production in non-EU countries, global emissions are further increased outside the EU because production in non-EU countries has generally higher emission intensities than the EU. This means that the reallocation of production results in higher global emissions even if total global production would remain constant. The location of production is thus an important determinant for emission changes in the agricultural sector. This is illustrated by our results of the scenario with a unilateral carbon tax in the EU agricultural sector, which show that the differences in emission intensities between EU and non-EU regions cause a net increase in global agricultural non-CO_2 emissions.

A unilateral carbon tax on agricultural production imposes higher cost on EU farmers compared to farmers in other countries, hence reducing the competiveness of EU farmers. Our results shows that a carbon tax in the EU reduces EU exports and increases imports, indicating the reduced competiveness in the EU farming sector. BCA could improve the situation on the EU market as imported products would also have to carry the entailed costs of carbon emissions, but EU farmers would still lose relative competiveness on the world market as the modelled BCA tariff is ineffective in export markets. Our scenario results show that the modelled BCA tariff has a significant impact on EU production of sheep and goat meat, which is almost restored to pre-tax levels with the BCA. For other parts of the agricultural sector the BCA is not sufficient to restore the competitiveness of EU agriculture.

In summary, our scenario results lead to the following conclusions:

a) BCA can partly offset the leakage of unilateral mitigation efforts, as shown in the scenario with a carbon tax in the EU in combination with a BCA tariff.
b) However the effectiveness of BCA is limited by the fact that trade diversion is happening outside the region which imposes the BCA.
c) In particular, while the BCA will limit the imports from regions with low GHG efficiencies (i.e. high emission intensities) to the EU, these GHG inefficient regions might cover the domestic supply loss of regions which export to the EU.
d) Our results suggest that in order to efficiently and effectively diminish emission leakage it requires policies also targeting the most important trading partners.
e) The results are sensitive to GHG emission intensities, showing the importance of both having detailed data on this and fostering the improvement of emission intensities.

As most of the emission leakage is due to increased beef production outside the EU, to satisfy the demand, change in some consumption patterns might also be necessary for an effective reduction of emission leakage.

A limitation in our paper comes from the fact that our analysis only covers non-CO_2 emissions, and would be more complete by adding CO_2 emissions and sinks from LULUCF. The reason is that the former are directly related to the UNFCCC common reporting category 'agriculture'. Including more emissions requires further model development, and by increasing the accuracy of the results such an extensions would enhance our understanding of this problem.

A major concern with implementing BCA measures is whether they are compatible with WTO rules and thus whether they induce retaliation measures from WTO partners. Several studies argue that BCA can be designed to comply with WTO rules. In our scenarios we also opt for a policy implementation (BCA import tariff differentiated by exporting country in combination with a domestic carbon tax), which in principle complies with WTO rules (Cosbey et al. 2019, Di Leva and Xiaoxin 2017, Mehling et al. 2017, Odell 2018).

The carbon tax in our scenarios is levied on the unit of agricultural products marketed, based on average CO_2-equivalent emissions occurring throughout the production process. The assumption of basing the tax on benchmark average emission intensities makes the practical implementation of the carbon tax easier. Taxing actual emissions, alternatively, would require setting up a monitoring system to measure the emissions of agricultural activities at the farm, with significantly higher implementation costs. The disadvantage of levying the carbon tax based on fix emission coefficients is that farmers are not directly incentivized to adjust the emission intensity of their production systems. Farmers' response to carbon tax is limited to production adjustments (changes in the production mix and in the level of agricultural supply), but mostly excludes possible improvements in production technology. In principle, carbon tax alternatives based on actual emissions would reduce the negative EU supply response, and thus could lead to smaller emission leakage effects than those simulated in our scenarios.

The redistribution of the tax revenue from the domestic carbon tax and the BCA measures could be an indirect source of increasing emission efficiency, if that tax revenue were redistributed to the farming sector, e.g. as a subsidy for adopting GHG emission mitigation technologies. The (subsidized) adoption of such technologies would lead to lower emission intensities of the EU agricultural production activities, and possibly larger total savings in agricultural emissions. We refrain from making assumptions on the possible redistribution of tax revenues in our scenarios, however, because providing domestic support for the farming sector is again subject to WTO rules, making the WTO-compatibility of the implemented BCA package more difficult to assess. Regarding the relative emission efficiency of the EU farming sector, our estimations indicate that EU agriculture is already relatively emission efficient in the global context. Transferring BCA tariff revenues to relatively less emission efficient countries, e.g. in the form of direct support for technology improvements, might increase the efficiency of BCA measures in curbing emission leakage. Such monetary transfers could not only increase the efficiency of BCA policies, but would also highlight their climate mitigation objective, leaving any hidden trade protectionist intentions aside.

6 References

Aichele, R., and G. Felbermayr. 2015. Kyoto and Carbon Leakage: An Empirical Analysis of the Carbon Content of Bilateral Trade. *The Review of Economics and Statistics* 97 (1):104-115.

Babiker, M.H. 2005. Climate change policy, market structure, and carbon leakage. *Journal of International Economics* 65 (2):421-445.

Branger, F., and P. Quirion. 2014. Would border carbon adjustments prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies. *Ecological Economics* 99:29-39.

Britz, W., and H.P. Witzke. 2014. *CAPRI model documentation 2014*. Edited by Wolfgang Britz and Hans Peter Witzke. Bonn: Institute for Food and Resource Economics University of Bonn.

Böhringer, C., E.J. Balistreri, and T.F. Rutherford. 2012. The role of border carbon adjustment in unilateral climate policy: Overview of an Energy Modeling Forum study (EMF 29). *Energy Economics* 34, Supplement 2:S97-S110.

Böhringer, C., J.C. Carbone, and T.F. Rutherford. 2018. Embodied Carbon Tariffs. *The Scandinavian Journal of Economics* 120 (1):183-210.

Böhringer, C., C. Fischer, and K.E. Rosendahl. 2014. Cost-effective unilateral climate policy design: Size matters. *Journal of Environmental Economics and Management* 67 (3):318-339.

Cosbey, A., S. Droege, C. Fischer, and C. Munnings. 2019. Developing Guidance for Implementing Border Carbon Adjustments: Lessons, Cautions, and Research Needs from the Literature. *Review of Environmental Economics and Policy* 13 (1):3-22.

De Cara, S., and P.-A. Jayet. 2011. Marginal abatement costs of greenhouse gas emissions from European agriculture, cost effectiveness, and the EU non-ETS burden sharing agreement. *Ecological Economics* 70 (9):1680-1690.

Di Leva, C.E., and S. Xiaoxin. 2017. The Paris Agreement and the International Trade Regime: Considerations for Harmonization. *Sustainable Development Law & Policy:* 17 (1):Article 4.

Elliott, J., I. Foster, S. Kortum, and G.K. Jush. 2013. Unilateral Carbon Taxes, Border Tax Adjustments and Carbon Leakage Reaching International Cooperation on Climate Change Mitigation. *Theoretical Inquiries in Law* 14:207-244.

Elliott, J., I. Foster, S. Kortum, T. Munson, F. Pérez Cervantes, and D. Weisbach. 2010. Trade and Carbon Taxes. *American Economic Review* 100 (2):465-69.

European commision. 2014. COMMISSION DECISION of 27 October 2014 determining, pursuant to Directive 2003/87/EC of the European Parliament and of the Council, a list of sectors and subsectors which are deemed to be exposed to a significant risk of carbon

leakage, for the period 2015 to 2019 *Official Journal of the European Communities L 308* (61):114-124.
European Commission. *Effort Sharing Decission*. European Commission, 15/04/2016 2016 [cited 25/04/2016. Available from http://ec.europa.eu/clima/policies/effort/index_en.htm.
European Parliament and the Council. 2018. Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013 (Text with EEA relevance). *Official Journal of the European Communities L 156* (61):26–42.
Fellmann, T., P. Witzke, F. Weiss, B. Van Doorslaer, D. Drabik, I. Huck, G. Salputra, T. Jansson, and A. Leip. 2018. Major challenges of integrating agriculture into climate change mitigation policy frameworks. *Mitigation and Adaptation Strategies for Global Change* 23 (3):451-468.
Fouré, J., H. Guimbard, and S. Monjon. 2015. Border carbon adjustment and trade retaliation: What would be the cost for the European Union? *Energy Economics*.
Grosjean, G., S. Fuss, N. Koch, B.L. Bodirsky, S. De Cara, and W. Acworth. 2016. Agriculture: Sleeping Beauty of EU Climate Policy? Overcoming Barriers to Implementation.
Hecht, M., and W. Peters. 2019. Border Adjustments Supplementing Nationally Determined Carbon Pricing. *Environmental and Resource Economics* 73 (1):93-109.
Himics, M., T. Fellmann, J. Barreiro-Hurlé, H.-P. Witzke, I. Pérez Domínguez, T. Jansson, and F. Weiss. 2018. Does the current trade liberalization agenda contribute to greenhouse gas emission mitigation in agriculture? *Food Policy* 76:120-129.
Holzer, K. 2016. WTO law issues of emission trading.*Working paper* 2016/1, World Trade Institute.
IPCC. 2006. *2006 IPCC guidelines for national greenhouse gas inventories, Prepared by the National Greenhouse Gas Inventories Programme*. Edited by H.S. Eggleston, Leandro Buendia, Kyoko Miwa, Todd Ngara and Kiyoto Tanabe. Vol. 2. Hayama, Japan: IGES.
Ismer, R., and K. Neuhoff. 2007. Border tax adjustment: a feasible way to support stringent emission trading. *European Journal of Law and Economics* 24 (2):137-164.
Jansson, T., I. Pérez Domínguez, and F. Weiss. 2010. Estimation of Greenhouse Gas coefficients per Commodity and World Region to Capture Emission Leakage in European Agriculture. In *119th EAAE Seminar*. Capri.
Juergens, I., J. Barreiro-Hurlé, and A. Vasa. 2013. Identifying carbon leakage sectors in the EU ETS and implications of results. *Climate Policy* 13 (1):89-109.
Kuik, O., and M. Hofkes. 2010. Border adjustment for European emissions trading: Competitiveness and carbon leakage. *Energy policy* 38 (4):1741-1748.
Larch, M., and J. Wanner. 2017. Carbon tariffs: An analysis of the trade, welfare, and emission effects. *Journal of International Economics* 109:195-213.
Leip, A., F. Weiss, T. Wassenaar, I. Perez, T. Fellmann, P. Loudjani, F. Tubiello, D. Grandgirard, S. Monni, and K. Biala. 2010. Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS).*Final report*, European Commission, Joint Research Centre.
M'barek, R., J. Barreiro Hurle, P. Buolanger, A. Caivano, P. CIianan, H. Dudu, M. Espinosa Goded, T. Fellman, E. Ferrari, S. Gomez Y Paloma, C. Gorrin Gonzalez, M. Himics, K. Elouhichi, A. Perni Llorente, G. Philippidis, G. Salputra, H.P. Witzke, and G. Genovese. 2017. Scenar 2030 - Pathways for the European agriculture and food sector beyond 2020.*Science for Policy report* EUR 28797 EN, JRC of the Europeean Commission.
Martin, R., M. Muûls, L.B. de Preux, and U.J. Wagner. 2014. On the empirical content of carbon leakage criteria in the EU Emissions Trading Scheme. *Ecological Economics* 105:78-88.

Mehling, M., H. van Asselt, K. Das, S. Droege, and C. Verkuijl. 2017. Designing Border Carbon Adjustments for Enhanced Climate Action. Climate Strategies.
Mehling, M.A., H. van Asselt, K. Das, and S. Droege. 2018. Beat protectionism and emissions at a stroke. *Nature* 559:321-324.
Monjon, S., and P. Quirion. 2011. A border adjustment for the EU ETS: reconciling WTO rules and capacity to tackle carbon leakage. *Climate Policy* 11 (5):1212-1225.
Odell, J.S. 2018. Our Alarming Climate Crisis Demands Border Adjustments Now. International Centre for Trade and Sustainable Development (ICTSD).
Perez Dominguez, I., T. Fellman, H.P. Witzke, T. Jansson, D. Oudendag, A. Gocht, and D. Verhog. 2012. Agricultural GHG emissions in the EU: an exploratory economic assessment of mitigation policy options *JRC Scientific and Technical Research Reports*, JRC of the European Commission.
Perez Domínguez, I., and T. Fellmann. 2015. The Need for Comprehensive Climate Change Mitigation Policies in European Agriculture. *EuroChoices* 14 (1):11-16.
Perez Dominguez, I., T. Fellmann, F. Weiss, H.P. Witzke, J. Barreiro Hurle, M. Himics, T. Jansson, G. Salputra, A. Leip, and T. Fellmann. 2016. An economic assessment of GHG mitigation policy options for EU agriculture (EcAMPA 2).*JRC Science for Policy Reports*, European Commission.
Richards, M.B., E. Wollenberg, and D. van Vuuren. 2018. National contributions to climate change mitigation from agriculture: allocating a global target. *Climate Policy*:1-15.
Rogelj, J., A. Popp, K.V. Calvin, G. Luderer, J. Emmerling, D. Gernaat, S. Fujimori, J. Strefler, T. Hasegawa, G. Marangoni, V. Krey, E. Kriegler, K. Riahi, D.P. van Vuuren, J. Doelman, L. Drouet, J. Edmonds, O. Fricko, M. Harmsen, P. Havlík, F. Humpenöder, E. Stehfest, and M. Tavoni. 2018. Scenarios towards limiting global mean temperature increase below 1.5 °C. *Nature Climate Change* 8 (4):325-332.
Smith, P., H. Clark, H. Dong, E. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari, O. Masera, and C. Mbow. 2014. "Agriculture, forestry and other land use (AFOLU)." In *Climate Change 2014: Mitigation of Climate Change. IPCC Working Group III Contribution to AR5*, 811-922. Cambridge University Press.
Van Doorslaer, B., P. Witzke, I. Huck, F. Weiss, T. Fellmann, G. Salputra, T. Jansson, D. Drabik, and A. Leip. 2015. An economic assessment of GHG mitigation policy options for EU agriculture.*JRC Technical Reports*, Joint Research Centre of the European Commission.
Wollenberg, E., M. Richards, P. Smith, P. Havlík, M. Obersteiner, F.N. Tubiello, M. Herold, P. Gerber, S. Carter, A. Reisinger, D.P. Vuuren, A. Dickie, H. Neufeldt, B.O. Sander, R. Wassmann, R. Sommer, J.E. Amonette, A. Falcucci, M. Herrero, C. Opio, R.M. Roman-Cuesta, E. Stehfest, H. Westhoek, I. Ortiz-Monasterio, T. Sapkota, M.C. Rufino, P.K. Thornton, L. Verchot, P.C. West, J.-F. Soussana, T. Baedeker, M. Sadler, S. Vermeulen, and B.M. Campbell. 2016. Reducing emissions from agriculture to meet the 2 °C target. *Global Change Biology* 22 (12):3859-3864.