The role of technology in avoiding leakage from unilateral mitigation targets in agriculture: the case of the EU

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Abstract

The effectiveness of unilateral greenhouse gas mitigation efforts has been put in doubt due to the so called carbon leakage effect both for industrial and agricultural sectors. In such scenario production shifts to world regions with no carbon constraint and the region which has imposed the carbon constraint substitutes its former domestic production by imports of these now relatively cheaper products, reducing economic activity but not changing consumption bundles. In this paper we investigate how technology can dampen this effect. For this we use the CAPRI partial equilibrium model of the EU agriculture together with its global spatial multi-commodity model calculating endogenously GHG emission coefficients for nitrous oxide and methane following the IPCC guidelines. For the rest of the world we use emission intensities calculated for the past based on emission and production data. Technology is modelled considering trend functions for the emission intensities in the rest of the world which are continued into the future. Our results show that while leakage exists and is increasing with the stringency of the GHG mitigation target of the EU, it can be mostly offset by allowing the ROW to adopt better technologies. To maximize its impact on reducing carbon leakage, technology transfer should focus on meat commodities and the Asia and Central and South American regions.

Introduction

On 23 October 2014, the European Council agreed on the domestic climate and energy goals for 2030. The agreement follows the main building blocks of the 2030 policy framework for climate and energy, as proposed by the European Commission in January 2014. A key element of the new policy framework is the reduction target for greenhouse gas (GHG) emissions, which the European Council agreed to be of at least 40% by 2030 compared to 1990 levels. As in the current EU climate and energy package, emission reduction obligations will be distributed between Member States (under the Effort Sharing Decision, ESD) and industry (under the Emission Trading Scheme, ETS). To achieve the overall 40% target, the sectors covered by the EU ETS are supposed to reduce their emissions by 43% compared to 2005 and emissions from sectors outside the EU ETS (i.e. the ones covered within the ESD) will need to be cut by 30% below the 2005 level. Furthermore, the agreement of the European Council states that the mitigation effort in the non-ETS sector would have to be shared 'equitably' between the Member States (Council of the European Union, 2014; European Commission, 2014a).

In order to achieve this target all sectors should contribute to the mitigation efforts. This paper investigates into the potential of the agricultural sector in the EU to mitigate its GHG emissions and in particular looks into the implications of such unilateral commitments in terms of global GHG reductions. Greenhouse gas emissions are a global public bad, the contribution of emissions towards climate change knows no national borders and, therefore, restricting the analysis of emissions to just one world region does not give the full picture of the mitigation potential of specific policies. In

[1] The authors are solely responsible for the content of the paper. 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

particular the effects of changing trade patterns on global emissions is of relevance, as climate action in one region can give raise to emissions in another region, or carbon, leakage. Carbon leakage occurs when production shifts from a carbon-constrained region to those regions that do not have such constraints, so that formerly domestically produced products are substituted by relatively cheaper imported products (Juergens et al., 2013). To measure carbon leakage we need additional data on the emissions of the rest of the world and their development, this poses additional modelling challenges.

According to GHG inventories of the EU-28 Member States, GHG emissions in the source category agriculture accounted for a total of 471 million tonnes of CO2 equivalents in 2012[2]. This represented 10.3% of total EU-28 GHG emissions in 2012 (Figure 1**Error! Reference source not found.**). Depending on the relative size and importance of the agricultural sector, the share of agriculture emissions in total national GHG emissions varies considerably within the EU Member States. The share is highest in Ireland (31%), Lithuania (23%) and Latvia (22%), and lowest in Malta (2.5%), Luxembourg and the Czech Republic (about 6% each). When looking at the total EU-28 agriculture GHG emissions it is also important to highlight how they are distributed amongst Member States (Figure **2**). France (19%), Germany (15%) and the United Kingdom (11%) together account for about 45% of total EU-28 agriculture emissions, followed by Spain and Poland (8% each), Italy (7%), Romania and Ireland (4% each) and the Netherlands (3%). On the other hand, eight Member States (Denmark, Belgium, Greece, Hungary, Czech Republic, Sweden, Austria, Portugal) have a share of around 2% each, six Member States (Bulgaria, Finland, Lithuania, Croatia, Slovakia, Latvia) a share of about 1% each, and four Members States have a share that is less than 0.5% in total EU-28 agriculture GHG emissions, namely Estonia (0.3%), Cyprus (0.2%), Luxembourg (0.1%), and Malta (with only 0.02%).

Figure 1. Breakdown of agricultural GHG emissions in the EU-28, 2012

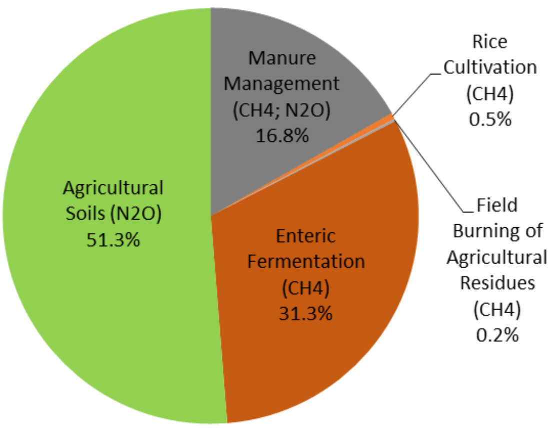
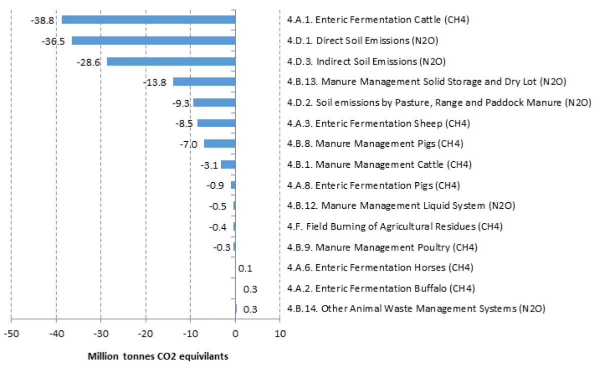


Figure 2. Absolute changes in GHG emissions by EU agriculture key source categories, 1990–2012 (million tonnes CO2 equivalents)



Source: EEA database (2015)

[2] All data is based on the latest available official data compiled by the European Environment Agency (EEA) and reported by the EU to the UNFCC (see EAA database set v16, published on 15 March 2015).

The historical developments of agriculture GHG emissions show a rather steady downward trend on the aggregated EU-28 level of -24%, from about 618 million tonnes CO2 equivalents in 1990 to about 471 million tonnes CO2 equivalents in 2012. While EU-15 emissions decreased by 15% (-68.4 million tonnes CO2 equivalents), EU-N13 emissions decreased by 45% (-78.8 million tonnes CO2 equivalents) over the period 1990 to 2012. The decrease in agricultural GHG emissions is attributable to several factors, but most of all to productivity increases and a decrease in cattle numbers, as well as improvements in farm management practices and also developments and implementation of agricultural and environmental policies. Furthermore, the developments have been considerably influenced by adjustments of agricultural production in the EU-N13 following the changes in the political and economic framework after 1990 (cf. European Commission 2009; EEA 2013). The relative reductions in EU-28 GHG emissions in the sector agriculture between 1990 and 2012 are less than reductions achieved in the sectors waste (-32%) and industrial processes (-31%) over the same time period, but higher than the trend in total EU GHG emissions, which decreased by 19% (without LULUCF).

Looking closer into the developments of agricultural GHG emissions per MS, dividing the trend into two time periods shows that the major part of the decreases was achieved in the period between 1990 and 2000 and that in most MS the reduction path significantly slowed down in the time period between 2001 and 2012. This holds especially for the EU-N13 MS, where due to the restructuring process GHG emissions decreased on the aggregated level by 44% between 1990 and 2000, but only by about 3% between 2001 and 2012. On the other hand, agricultural GHG emissions on the aggregated EU-15 level decreased more between 2001 and 2012 (-9%) than between 1990 and 2000 (-5%). At aggregated EU-28 level, agriculture GHG emissions decreased by16% in the period 1990 to 2000 and by 8% between 2001 and 2012.

Considering the different sources of GHG emissions in the agriculture sector of the EU-28 in 2012, the share is divided between the following source categories (Figure 1): agricultural soils (51%; N2O), enteric fermentation (31%; CH4), manure management (17%; both CH4 and N2O), rice cultivation (0.5%; CH4) and field burning of agricultural residues (0.2%; CH4). All sources experienced a decrease during the 1990 - 2012 period. The largest absolute reductions of methane occurred in the key source enteric fermentation of cattle, decreasing by 38.8 million tonnes CO2eq (-24%) between 1990 and 2012 at EU-28 level, followed by a decrease of 8.5 million tonnes CO2eq (-33%) in enteric fermentation of sheep. The main driving force for methane emissions from enteric fermentation is the number of animals, which decreased for both cattle and sheep in the EU-28 over the time period considered. The decrease in animal numbers not only lead to decreases in enteric fermentation but also comprised decreased methane emissions from the management of their manure. Thus the reductions in methane emissions can mainly be attributed to significant decreases in cattle numbers, which was influenced by the CAP (like e.g. the milk quota and the introduction of decoupled direct payments) and also followed increases in animal productivity (milk and meat) and related improvements in the efficiency of feed use. In this context also the adjustments in agricultural production in the EU-N13 following the changes in the political and economic framework after 1990 have been important.

Largest absolute reductions of nitrous oxide emissions in the EU-28 occurred in soil emissions, with direct soil emissions decreasing by 36.5 million tonnes CO2eq (-22%) and indirect soil emissions by 26.6 million tonnes CO2eq (-26%) between 1990 and 2012 (Figure **2**). The main driving force of nitrous oxide emissions from agricultural soils is the application of mineral nitrogen fertilizer and organic nitrogen from animal manure. Thus, the decrease in nitrous oxide emissions from soils is mainly attributable to reduced use of mineral nitrogen fertilizers (following productivity increases but also influenced by the CAP, e.g. the Mac Sharry reform) and decreases in the application of animal manure (a direct effect of declining animal herds).

Carbon leakage has been widely studied for industrial sectors under the ETS (Martin et al., 2014; Sartor et al., 2014; Schmidt and Heitzig, 2014) concluding that the risk exists but its intensity varies according to differences in production processes, technologies and fuel mix; process emissions; recycling rate differences; and product mix differences. The issue of carbon leakage of agricultural policy measures in the EU agriculture has already been highlighted by Pelikan et al. (2015). The authors linked the CAPRI supply module for the EU with the GTAP model for global trade and land use and find that attempts to enhance biodiversity in Europe via agricultural policy can have unintended consequences in the rest of the world increasing GHG emissions.

In this paper we use the CAPRI model to see the unintended consequences of unilateral mitigation targets for EU agriculture in terms of GHG emissions in the rest of the world. In addition we investigate how technology transfer can dampen this effect, via increased GHG efficiency of agricultural production. The rest of the paper is structure as follows; first we present the basics of the CAPRI model and its expansion to incorporate greenhouse gas emissions both in the EU and the rest of the world and the simulation of technology improvements. Then we present the results for major agricultural commodities and GHG for three different scenarios (unilateral mitigation targets of 15, 20 and 25% compared to 1990) under two assumptions of technology development. The paper concludes with some policy implications and areas for further research.

Methodology

For the quantitative assessment of mitigation policies in the agricultural sector we employ the CAPRI modelling system. Detailed information on the CAPRI modelling system is documented in Britz and Witzke (2014) and can be found on the CAPRI-model homepage[3]. In this section we present a brief overview on the CAPRI model and the general calculation of agricultural GHG emissions in CAPRI. We also describe the details of the estimation of commodity-based emission factors for non-EU countries (needed to account for emission leakage).

CAPRI is an economic large-scale comparative-static agricultural sector model with a focus on the EU (at NUTS 2, Member State and aggregated EU-28 level), but covering global trade with agricultural products as well (Britz and Witzke, 2014). CAPRI consists of two interacting modules: the supply module and the market module. The supply module consists of about 280 independent aggregate optimisation models, representing regional agricultural activities (28 crop and 13 animal activities) at Nuts 2 level within the EU-28. These supply models combine a Leontief technology for intermediate inputs covering a low and high yield variant for the different production activities with a non-linear cost function which captures the effects of labour and capital on farmers' decisions. This is combined with constraints relating to land availability, animal requirements, crop nutrient needs and policy restrictions (e.g. production quotas). The non-linear cost function allows for perfect calibration of the models and a smooth simulation response rooted in observed behaviour (Pérez Dominguez et

[3] www.capri-model.org

al., 2009; Britz and Witzke, 2014). The market module consists of a spatial, non-stochastic global multi-commodity model for 47 primary and processed agricultural products, covering 77 countries in 40 trading blocks. Bi-lateral trade flows and attached prices are modelled based on the Armington assumption of quality differentiation (Armington, 1969). The behavioural functions for supply, feed, processing and human consumption in the market module apply flexible functional forms, so that calibration algorithms ensure full compliance with micro-economic theory. The link between the supply and market modules is based on an iterative procedure (Pérez Dominguez et al., 2009; Britz and Witzke, 2014).

The CAPRI modelling system is adapted to calculate activity based agricultural emission inventories. CAPRI is designed such as to capture the links between agricultural production activities in detail (e.g. food and feed supply and demand interactions or animal life cycle), and based on the production activities, inputs and outputs define agricultural GHG emission effects. The CAPRI model incorporates a detailed nutrient flow model per activity and region (which includes explicit feeding and fertilising activities, i.e. the balancing of nutrient needs and availability) and calculates yields per agricultural activity endogenously. With this information, CAPRI is able to calculate endogenously GHG emission coefficients following the IPCC guidelines (cf. IPCC, 2006). The IPCC guidelines provide various methods for calculating a given emission. These methods all use the same general structure, but the level of detail at which the calculations are carried out can vary. The IPCC methods for estimating emissions are divided into 'Tiers', encompassing different levels of activity, technology and regional detail. Tier 1 methods are generally straightforward (activity multiplied by default emissions factor) and require less data and expertise than the more advanced Tier 2 and Tier 3 methods. Tier 2 and Tier 3 methods have higher levels of complexity and require more detailed country-specific information on, for example, technology type or livestock characteristics. In CAPRI a Tier 2 approach is generally used for the calculations, however, for activities where the respective information is missing a Tier 1 approach is applied to calculate the GHG emissions (e.g. rice cultivation). A more detailed description of the general calculation of agricultural emission inventories on activity level in CAPRI (without the inclusion of technological mitigation options) is given in Pérez Domínguez (2006) and Leip et al. (2010). Reporting of emissions can take place by aggregating to the desired aggregation level. The output as given in this paper report mimics the reporting on emissions by the EU to the UNFCCC (seeTable 1).

Table 1. Reporting items to the UNFCCC and emission sources calculated and reported in CAPRI

	UNFCCC Reporting Sector 4 Agriculture	CAPRI reporting and modelling	
Methane	A: Enteric fermentation	CH4ENT	Enteric fermentation
	B: Manure management	CH4MAN	Manure management
	C: Rice cultivation	CH4RIC	Rice cultivation
Nitrous oxide	B: Manure management	N2OMAN	Manure management (stable and storage)
	D: Agricultural soils		
	D1: synthetic fertilizer	N2OSYN	Synthetic fertilizer
	D2: Animal waste	N2OAPP	Manure management (application)
	D4: Crop residuals	N2OCRO	Crop residuals
	D5: Cultivation of histosols	N2OHIS	Histosols
	D6: Animal production	N2OGRA	Excretion on pasture
	D7: Atmospheric deposition	N2OAMM	Deposition of ammonia
	D8: Nitrogen leaching	N2OLEA	Emissions due to leaching of nitrogen
	E: Prescribed burning of savannahs		not covered in CAPRI
	E: Field burning of agricultural residues		not covered in CAPRI

While EU emissions in CAPRI are based on specific agricultural activities (e.g. kg of methane or nitrous oxide per head or per hectare), this is not the case for the non-EU regions, where only tradable agricultural commodities are covered. Therefore, for the EU trade partners in the model the emission accounting needs to be done on a product basis (e.g. kg of methane or nitrous oxide per kg or litre of product).[4]

For the EU, activity based emission intensities are derived from the activity for a given year. The underlying CAPRI supply model incorporates endogenous technological change (i.e. growth in yields, application of new technologies) that allow emission factors to improve (decrease) with time. For the rest of the world emission intensities can be calculated for the past based on emission and production data from FAOSTAT.

For scenario analysis, the emission factors per commodity previously estimated for each non-EU region are multiplied with production to compute total emissions per region. An exception is the EU, where more detailed emission inventories are computed directly in the supply model in each simulation, allowing the emission intensities per commodity to change endogenously with changing input use, regional distribution of production, or application of mitigation technologies. In this report carbon leakage is measured as the ratio of total amount of increased emissions in non-EU regions with respect to the emission mitigation effort in the EU.

However this does not allow incorporating technological change (i.e. improved emission efficiency) for the rest of the world. As the impacts are evaluated several decades down the road, if this is overlooked emission leakage will be overestimated. To solve this, trend functions are estimated for the emission intensities in the rest of the world using IPCC Tier 1 coefficients are as prior information

[4] For example pig breeding and pig fattening are activities in the EU (i.e. supply model of CAPRI) while the commodity pork meat is traded between the EU and non-EU origins/destinations (i.e. market module of CAPRI. The same applies to cattle herds (EU activities) and their derived beef and milk products (traded commodities).

within a robust Bayesian estimation framework (Jansson et al. 2010; Jansson et al. 2014) combining data on production quantities and emission inventories from FAOSTAT. The scenario where past trends are extrapolated into the future is named "technology" and this is so as we consider it would mimics a situation were developed countries would allocate climate funding to greenhouse gas technology adoption in the rest of the world.

CAPRI is a comparative static model that requires a projected equilibrium state of the economy in order to perform simulation exercises in a selected year. For the EU, the supply and market models of CAPRI are calibrated to the European Commission's medium-term prospects for EU Agricultural markets and income[5] and extended to the projection year 2030. The following targets are considered in the calibration: supply, demand, production, yields and prices. The final outcome of the calibration process is the CAPRI baseline, which provides the benchmark for any further comparative static simulation exercise. The CAPRI baseline used is calibrated to the European Commission's prospects for agricultural markets and income (European Commission, 2014b). A detailed description and discussion of the CAPRI calibration process is given in Himics et al. (2014). This baseline constitutes the reference scenario, to which the GHG mitigation policy scenarios are compared to.

Besides the calibration process the baseline also incorporates assumptions about the exogenous variables needed for the CAPRI modelling system. These variables may be classified as policy or market assumptions. Regarding policy assumptions, the CAPRI baseline used for this report incorporates agricultural and trade policies approved up to 2015. The measures of the Common Agricultural Policy (CAP) are covered, including measures of the latest 2014-2020 reform (direct support measures implemented at Member State or regional level and the abolition/expiry of the milk and sugar quota systems). The CAPRI baseline does not anticipate any potential WTO agreement in the future, and no assumptions are made concerning bilateral trade agreements that are currently under negotiation. Limits on nitrogen application as a consequence of the Nitrate Directive are also taken into account and some elements of the 'greening package' of the CAP such as crop diversification are also captured. The policy and market assumptions in the reference scenario are further outlined in Table 2 and Table 3.

[5] These are derived with the AGLINK-COSIMO model and subject to an intensive validation review. A detailed description of the European Commission's outlook process is given in Nii-Naate (2011) and Araujo Enciso et al. (2015).

Table 2. Core policy assumptions for the CAPRI October 2015 baseline.

PILLAR I		
Instrument	**Base year 2008**	**Baseline 2030**
Direct payments	As defined in 2003 reform and 2008 Health Check (HC); covering SFP or (SAPS)	2013 reform (partially) implemented
Decoupling	Historical/Regional/Hybrid schemes	Basic Payment Scheme
Coupled direct payment options	As defined in 2003 reform (including Article 68/69 and CNDP)	VCS according to the options notified by MS up to 01/08/2014*
Redistributive payment	NA	Not implemented
Young Farmer Scheme	Not implemented	Not implemented
Green Payment	NA	Green Payment component granted without restriction (only limitation: no conversion of permanent grassland)*
Capping	Modulation implemented	Implemented according to 2013 reform. Capped budget redistributed over RD measures
Convergence	NA	included
PILLAR II		
Instrument	**Base year 2008**	**Baseline**
Agri-environmental schemes	Less Favoured Areas (LFA) and Natura 2000 payments	Areas with Natural Constraints (ANC) and Natura 2000
Business Development Grants / investment aid	Not considered	Not considered
Common Market Organization		
Instrument	**Base year 2008**	**Baseline**
Sugar quotas	Yes	Abolition of the quota system in 2017
Dairy quotas	Yes	Quota system expires in 2015
Tariffs, Tariff Rate Quotas	Yes	Maintained at current implementation level or schedule
Export Subsidies	Yes	Not applied in 2030

* Market effects included via calibration to European Commission (2014)

Table 3. Core macroeconomic and market assumptions for the CAPRI October 2015 baseline

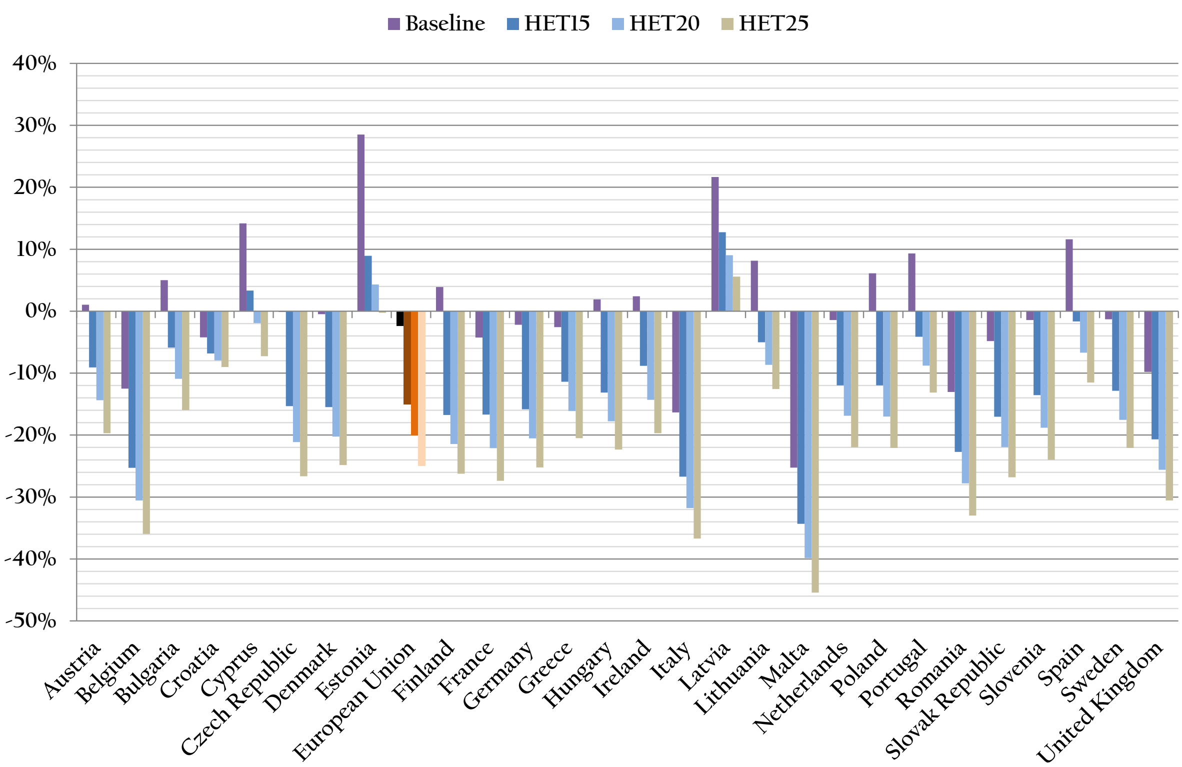
Variable	**Source**	**Determines…**
Macroeconomics (inflation, GDP)	PRIMES for EU, AGLINK/FAO/IFPRI elsewhere	… some nominal prices, position of demand functions, starting point for future simulations
Demographics	PRIMES for EU, AGLINK/FAO/IFPRI elsewhere	… position of demand functions, starting point for future simulations
Market balances for EU	European Commission (2014), supplemented with national/industry sources, sometimes defined by constrained trends	… target values for CAPRI trend estimator (e.g. beef supply)
World markets	European Commission (2014)/FAO/IFPRI projections plus data consolidation	… international market variables, position of behavioural functions, starting point for simulations
Biofuel policy	European Commission (2014)/F.O. Licht/COMEXT	…implicitly harmonized with those in EC MTO through calibration to biofuel supply/use and trade
Yields	European Commission (2014)/FAO/IFPRI or constrained trends	… market results, position of behavioural functions, starting point for simulations
Technological progress	Often own assumptions (e.g. max yields, 0.5% input saving p.a.), sometimes taken from IIASA studies (emission controls)	… market results, position of behavioural functions, starting point for simulations
Fertiliser use	European Fertilizer Manufacturers Association projections and over-fertilisation/availability parameter trends	… environmental indicators, farm income

Compared to this baseline, three mitigation targets were implemented imposing a compulsory reduction of agriculture GHG emission in the EU-28 of -15; -20 and -25 % in the year 2030 compared to 2005 (HET15, HET20 and HET25 respectively). The overall target is translated into heterogeneous targets per Member States according to a cost-effective allocation[6].

Results

We focus first on the impacts of the mitigation targets on EU agricultural GHG emissions, and agricultural activity levels. As presented in Figure **3** at EU level there is no additional abatement to the target setting in any of the scenarios, showing that currently there are no incentives for additional mitigation. However there is no homogenous mitigation across Member States reflecting the heterogeneity of agricultural production and abatement costs but also on the changes which are forecasted to occur under the baseline scenario. This explain for example why Latvia and Estonia have positive change in emissions driven by the baseline projections (+28% and +21% increase in GHG emissions respectively) or the high mitigation or Italy (-16% in the baseline).

Figure 3. Changes in agriculture GHG emissions per EU Member State in 2030 compared to 2005



In terms of agricultural activity Table **4** shows that, as a general rule, EU-28 activity levels decrease parallel to the mitigation target. Again, results not shown, the impact on activities at MS level is quite diverse, which is attributable to the following factors: (i) the specific mitigation target for the MS, and (ii) the relative strength of the sector. All scenarios show generally higher decreases in hectares or herd sizes than in production, indicating some considerable efficiency gains. The gains in efficiency might be attributed to the fact that less effective/productive areas and animals are usually taken out of production first, while more productive areas and animals will be kept.

[6] This allocation is obtained based on the introduction in CAPRI of a carbon price of 50 €/t CO_2 equivalents.

In all scenarios the biggest effects for production activities generally take place in the livestock sector of the EU-28, with the herd size of beef meat activities being most affected. For example in the HET20 scenario, EU-28 beef herd decreases by 16% and beef production by 9%. This effect could be higher without border protection measures. In all scenarios beef herd size decreases more than production. Results at MS level generally confirm the scenario trends indicated at aggregated EU-28 level. Relative reductions in beef herd sizes are considerably higher in EU-N13 than in the EU-15 MS (e.g. in HET20: -26% EU-N13 and -15% EU-15). In the HET20 scenario, for the EU-N13 highest (relative) decreases in herd size and production are projected to take place in Estonia, Lithuania, Hungary and Czech Republic. In the EU-15, Denmark shows the highest decrease in both beef herd size (-40%) and production (-16%), followed by Greece and the Netherlands (around -24% herd size and -8% production).

The dairy sector is generally less affected than the beef meat sector, with a reduction of the EU dairy herd size between 1.9% (HET15) and 5.2% (HET15). In general, results at MS level follow the developments indicated at EU-28 level.

Despite the fact that the mitigation target leads to a substantial increase in set aside and fallow land in the EU-28 in all policy scenarios, effects on crop production are rather moderate in all scenarios, with agricultural area in the EU-28 decreasing between 1.6% (HET15) and 5.1% (HET25). At MS level, in the HET20 scenario, cereal area is most affected in Finland, Slovenia, and Germany, while for Ireland an increase in area and production is projected.

Table 4.Change in area, herd size and supply for the EU-28 for activity aggregates of mitigation targets

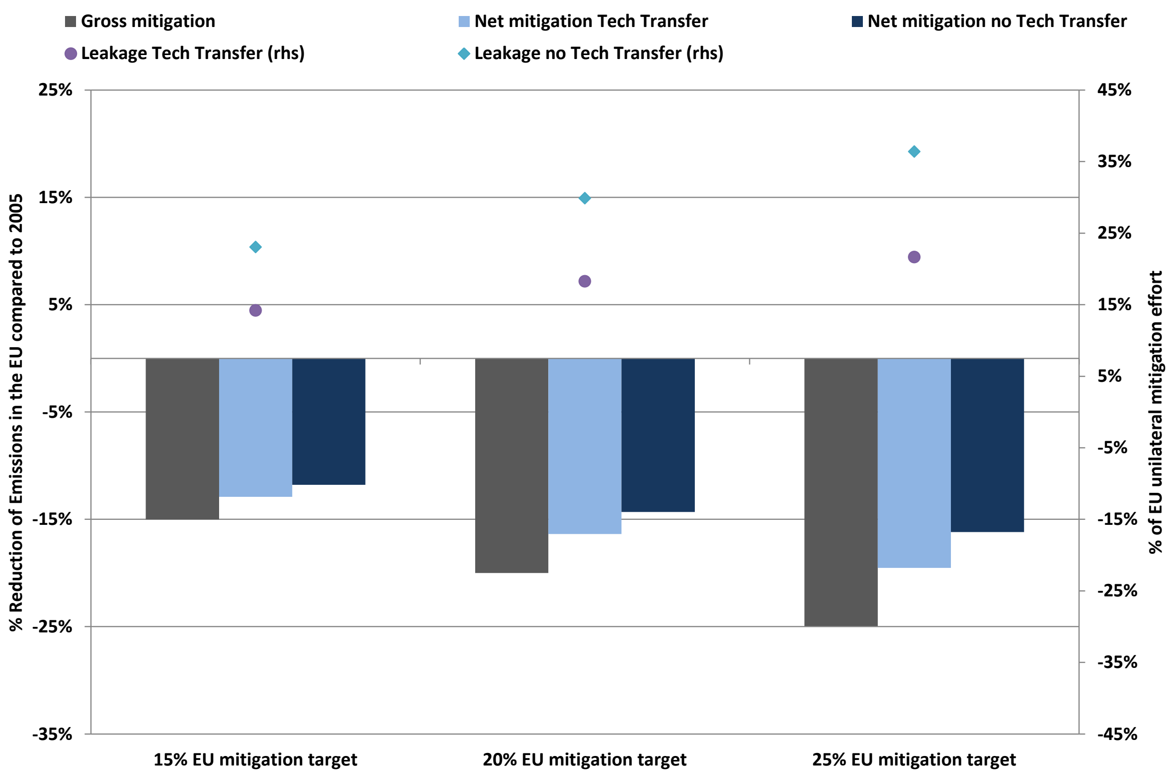
	REF		HET15		HET20		HET25	
	Hectares or herd size	Supply	Hectares or herd size	Supply	Hectares or herd size	Supply	Hectares or herd size	Supply
	1000 ha or hds	1000 t, 1000 ha	%-diference to REF					
Utilized agricultural area	180,898	n.a.	-1.6%	n.a.	-3.1%	n.a.	-5.1%	n.a.
Cereals	57,271	65,514	-2.6%	-1.7%	-4.4%	-2.8%	-6.9%	-3.4%
Oilseeds	12,040	13,872	-1.3%	-0.1%	-2.5%	-0.3%	-4.1%	-0.3%
Other arable crops	5,656	n.a.	-0.7%	n.a.	-1.2%	n.a.	-2.1%	n.a.
Vegetables and Permanent crops	16,846	n.a.	0.0%	n.a.	0.1%	n.a.	0.1%	n.a.
Fodder activities	82,230	42,261	-4.1%	-6.0%	-7.3%	-10.7%	-11.5%	-15.8%
Set aside and fallow land	6,856	n.a.	30.8%	n.a.	46.5%		68.5%	n.a.
Dairy cows	21,517	172,726	-1.9%	-1.1%	-3.4%	-2.0%	-5.2%	-3.1%
Beef meat activities	17,985	18,910	-9.1%	9.5%	-16.0%	17.9%	-24.4%	28.9%
Pig fattening	233,781	22,653	-2.2%	-2.2%	-4.0%	-4.1%	-6.3%	-6.5%
Pig Breeding	11,897	238,852	-2.1%	-2.2%	-3.8%	-4.0%	-6.2%	-6.3%
Milk Ewes and Goat	76,341	4,502	-4.7%	-3.4%	-9.1%	-7.1%	-14.8%	-12.0%
Sheep and Goat fattening	44,235	754	-4.6%	-4.4%	-8.8%	-8.3%	-14.1%	-13.3%
Laying hens	545	8,244	-1.1%	-0.9%	-2.0%	-1.7%	-3.3%	-2.8%
Poultry fattening	6,882	14,531	-0.6%	-0.7%	-1.2%	-1.3%	-2.1%	-2.3%

Note: na = not applicable; total supply of beef includes beef from suckler cows, heifers, bulls, dairy cows and calves (carcass weight)

The mitigation efforts which are centred in production reductions lead to increased exports as food demand is considered to remain more or less constant at the aggregated level. Following the production and price developments, we observe a worsening of the net trade position in the EU in all scenarios,. The largest changes in imports in % changes can be observed for meats, but with trade representing a very small share of domestic production. Increased imports, and thus production, in the rest of the world results in increased GHG emissions too, the magnitude of which depend on how technological progress is assumed to happen. Increased emissions range from 8.4 million tonnes CO2 equivalent for the 15% EU unilateral mitigation target assuming technological improvements, to 35 million tonnes CO2 equivalent for the 25% unilateral mitigation target without technological improvements. These figures have an important impact on the net mitigation results of EU policies.

Our results show that in the absence of technological transfer there is a significant leakage of emissions to the rest of the world when the EU unilaterally sets mitigation targets for its agricultural sector (Figure 4). Depending on the ambition of the target, between one in five and one in three tonnes abated in the EU is shifted to the rest of the world as production in the EU is replaced by imports. As expected, the biggest impacts of the modelled EU mitigation efforts happen in those activities that are more emission intensive such as beef and dairy. Impacts on herds are more significant than those in production as yield improvements are modelled endogenously in CAPRI and partly compensate the reduction in animal numbers.

Figure 4. Emission mitigation and leakage as % of gross mitigation for the different scenarios considered.

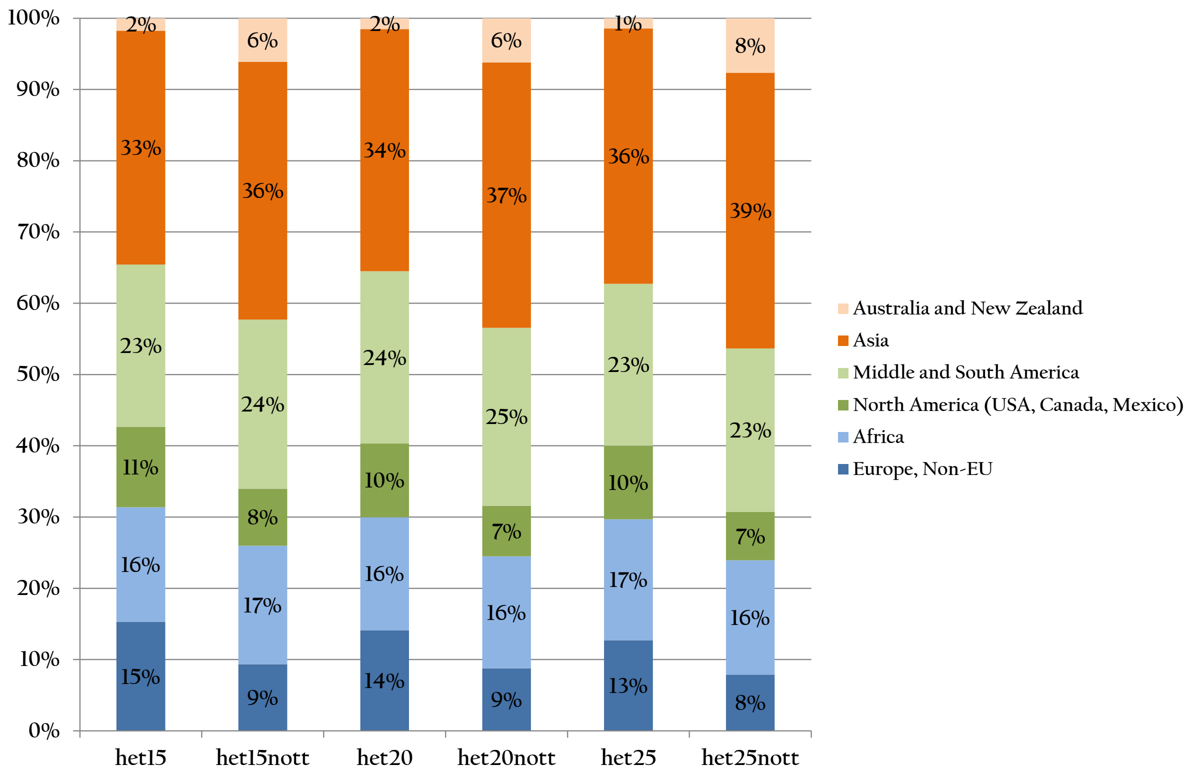


Note: Gross mitigation is the reduction of emissions in the EU. Net mitigation is the reduction of emissions in the EU plus the increase in the rest of the world. Technology improvement is modelled allowing production systems in the rest of the world to improve and become more efficient and less emission intensive over time Leakage rate is calculated as the share of emissions reduced in the EU that are offset by increases in the rest of the world.

However, once we assume technological improvement and allow the improvement of GHG emission intensities in the rest of the world, emission leakage is significantly reduced (from 9% for the 15% mitigation target to 15% for the 25% mitigation target) (figure 1). Despite the fact that some areas of the world have a bigger potential to benefit from technological improvement, in our modelling approach this is somehow hidden by the fact that future improvements are based on past performance and thus lagging regions with higher emission coefficients are restricted from a faster catching-up potential.

From a geographical perspective the biggest emission leakage occurs due to production increases in Asia, Middle and Central America, which account for nearly 60% of all the additional emissions (Figure 5). The biggest change from the inclusion of an increased emission efficiency assumed resulting from technological improvement happens in Australia and New Zealand and Asia where historical improvements of emission intensity have been higher. On the other hand, the weight of Non-EU Europe is higher; therefore additional technological improvement to that region would be warranted.

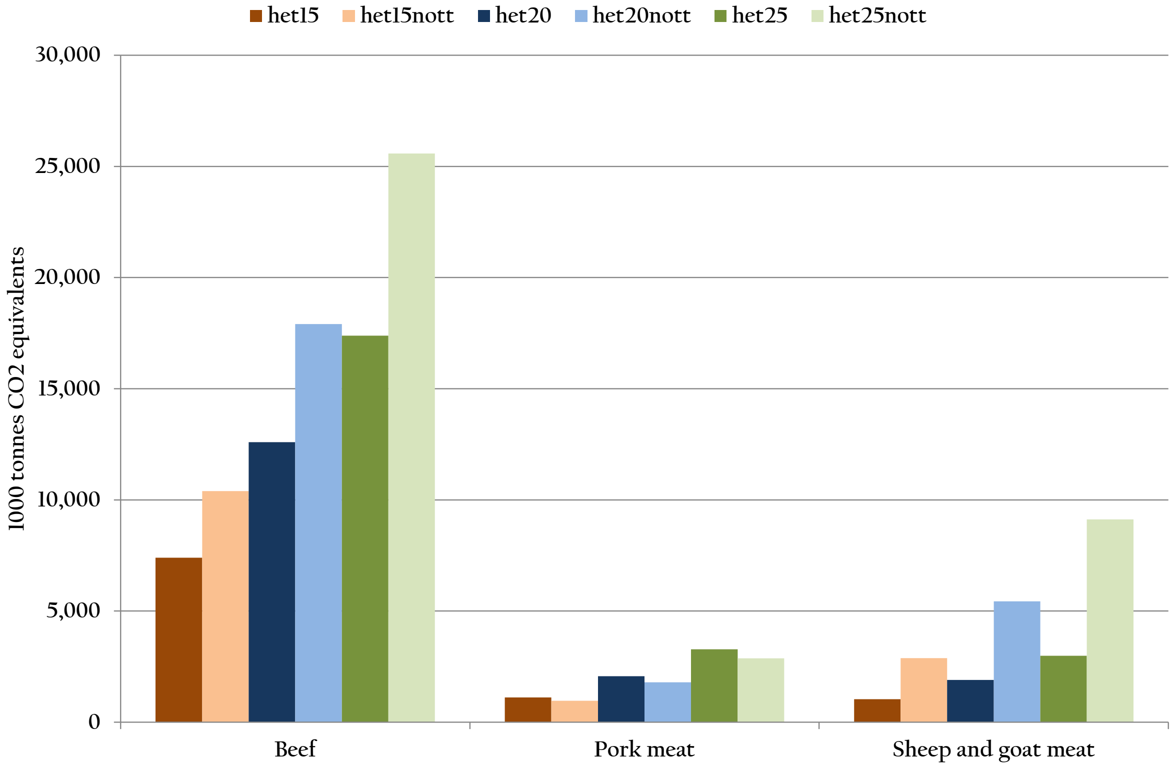
Figure 5. Distribution of leaked emissions by world region for different scenarios



Note: HETXX refers to the unilateral emission reduction target for EU agriculture; NOTT refers to the scenarios where emission intensities for the rest of the world is not updated.

As far as commodities are concerned, most of the leakage happens for meat products. If we look into the different types of meat (Figure 6) that are traded we can see that the biggest impact of considering technological improvement in emission intensity happens for sheep and goat meat in relative terms (64% impact), while the biggest absolute difference happens for beef (mitigation of 3 million tonnes of CO_2 equivalent). For poultry and pork intensification of production has meant that emission intensity has grown with time and therefore considering technological developments increases the rate of leakage.

Figure 6. Emission leakage associated with meats trade under different scenarios



Note: HETXX refers to the unilateral emission reduction target for EU agriculture; NOTT refers to the scenarios where emission intensities for the rest of the world is not updated.

Conclusion

In this paper we have looked into the potential of the EU agricultural sector to contribute to the mitigation of greenhouse gas emissions and the risk of carbon leakage deriving from unilateral commitments with no changing consumption patterns. The CAPRI model has been used to simulate 3 scenarios considering a 15%, 20% and 25% mitigation target by 2030 compared to 2005 and a world were emission intensity from agricultural production improves with time or not. We find that leakage is a legitimate concern; however its relative size can decrease significantly if the rest of the world catches up with more GHG efficient production techniques.

These results have clear policy implications in order to maximize the efficiency of unilateral GHG mitigation targets in the agricultural sector. First, the results highlight that it is necessary to also use climate finance to provide technological improvement for a GHG efficient agricultural production in in the rest of the world (especially developing countries). This is particularly relevant to less developed countries in Asia and Central and South America. Moreover, the technological improvement should focus on the livestock sector, which is where most of the emission leakage occurs, both as a result of higher EU imports (mainly for beef as the EU becomes a net importer) or lower EU exports (mainly for dairy, where EU exports fall by a maximum of 13%).

This paper is a first approximation to the issue of the role of technology in preventing leakage in agricultural related emissions from unilateral mitigation targets. Future improvements to the model will allow for simulating more targeted technological development options and technology absorption capacities in different world regions.

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