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Assessing the Importance of Technological non-CO2 GHG Emission Mitigation Options in EU Agriculture with the CAPRI model

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Abstract

The European Commission started to reflect on a new policy framework on climate and energy for 2030. Identifying the best options for agriculture to contribute to future GHG emission reductions in the EU requires a comprehensive analysis of a wide range of possible policies, technological and management measures. In this context the CAPRI model has been further improved with respect to GHG emission accounting and especially regarding the endogenous implementation of technological mitigation options. In this paper we present the methodology of the new model features and highlight the importance of including endogenous technological GHG emission mitigation options in the model analysis.

Results of illustrative emission mitigation scenarios show that different assumptions on the availability and uptake of technologies alter the scenario outcome significantly. The analysis indicates that possible negative impacts of mitigation policies on agricultural production and trade can drastically be reduced when technological mitigation options are available to farmers. This is a strong signal for enhanced research and development in the area of technological mitigation options, as well as policies that promote their diffusion.

Keywords: GHG emissions, climate policy, CAPRI model, EU agriculture, mitigation

1. Introduction

The agricultural sector is a large contributor of non-CO_2 GHG emissions, namely methane (CH_4) from ruminants and nitrous oxide (N_2O) from fertilizer use and management. According to greenhouse gas (GHG) inventories of the EU-27 Member States, agricultural GHG emissions accounted for 461 million tonnes of CO_2 equivalent in 2011, representing about 10% of total EU GHG emissions in 2011 (EEA, 2013). After transport and the residential and commercial sectors, it is the largest contributor of emissions in the so-called non-ETS sectors (i.e. the sectors not covered by the EU Emission Trading Scheme, ETS), and as such it is expected also to contribute to future emissions reductions in the EU. This raises the question on how the EU's agricultural sector would be affected if it would be included in binding emission reduction commitments, as for instance discussed in the EU in the context of the policy framework for climate and energy for 2030 (European Commission 2014a). In this context it is crucial to find options that allow to position agriculture to further contribute to achieving reductions in GHG emissions, while at the same time ensuring that the competitiveness of EU agriculture is not compromised. Identifying the best options requires a comprehensive analysis of a wide range of possible policy, technological and management measures. The CAPRI (Common Agricultural Policy Regional Impact Analysis) modelling system has already been used in some studies for the exploratory assessment of GHG mitigation policies (e.g. Pérez Dominguez, 2006; Leip et al., 2010; Pérez Dominguez et al., 2012). However, CAPRI so far lacked a full endogenous implementation of technological mitigation options (i.e., technical and management-based GHG mitigation measures) in the modelling system, which likely lead to an overestimation of the impact of potential GHG mitigation obligations on the agricultural sector in the EU. To overcome this shortcoming and to enable CAPRI to contribute to future impact assessments, the model has been further improved with respect to GHG emission accounting and specifically regarding a full endogenous implementation of technological mitigation options. In this paper we present the methodology of the new features in the CAPRI model, specifically comprising improved GHG emission accounting features as well as the endogenous implementation of technological mitigation options. To highlight the importance of the technological GHG emission mitigation options in the context of agricultural GHG emission reductions, we illustrate the new model features by two emission mitigation scenarios that achieve a non-

CO_2 GHG reduction of 20% in 2030 in agriculture compared to 2005. These scenarios are looking at the agriculture sector non-CO_2 emissions in isolation and do not reflect any interactions with other mitigation activities in other sectors, including for instance the impact of CO_2 emissions related to Land Use, Land Use Change and Forestry sectors. As such they do not reflect mitigation policies that are already agreed on or currently under formal discussion in the EU.

2. Methodology

CAPRI is an economic large-scale comparative-static agricultural sector model, with a focus on the EU (at NUTS2, Member State and aggregated EU-27 level), covering also global trade of agricultural products (Britz and Witzke, 2012). The regional supply models capture links between agricultural production activities in detail, which makes CAPRI suitable for the analysis of GHG emissions by thoroughly calculating activity-based agricultural emission inventories (Pérez Dominguez, 2006). In previous GHG mitigation policy analyses in CAPRI (Pérez Dominguez et al., 2012), only a few technological mitigation options have been implemented and in an entirely exogenous way. For this study, the calculation of GHG emission inventories in the CAPRI model has been further improved. GHG mitigation technologies have been rendered endogenous choice variables. Their number has been extended to include most of the measures that are also used in the GAINS model (GAINS 2013)[1] into options in the CAPRI model: farm scale anaerobic digestion, community anaerobic digestion, rice related options like intermediate aeration of continuously flooded rice, propionate precursors, antimethanogenic vaccination, good practice savings of fertiliser use, discontinuation of histosols' cultivation, nitrification inhibitors, timing of fertilization, precision farming, and changes in the composition of animals' diet (feed).

Modelling the response of GHG emissions in agriculture to economic incentives and policies is a challenge that is typically addressed only with a number of simplifications. The complexity is due to several factors, for example (1) production occurs in a farm population that is heterogeneous across space, size classes and specialisation; (2) the product mix may be changed flexibly in case of price changes, productivity changes or policy measures (CAP premiums and side conditions for them); (3) emissions of various types are linked to the composition and volume of production, as well as to the choice of mitigation technologies; (4) the cost of mitigation technologies indirectly determines the profitability of a certain specialisation within agriculture.

As a consequence of this complexity, frequently made simplifications include (1) only a subset of mitigation options is considered in the context of an otherwise detailed sector model (in the GLOBIOM model (Havlik et al., 2011)); (2) a rich description of the mitigation technologies is considered but with a given set of emission causing activities (e.g. in the GAINS model, see GAINS, 2013).

In this study, we make a first attempt to endogenise the choice among selected mitigation options within the CAPRI model (Britz and Witzke, 2012). The agents in the regional programming models representing the European farm sector are assumed to maximise their income. However, various factors constrain the level of production activities (e.g., the number of animals or hectares cultivated with some crop) and the use of mitigation technologies. These factors include land availability, fertilization requirements of the cropping systems versus organic nutrient availability, feed requirements in terms of dry

[1] This research therefore owes a lot to previous work of the GAINS team and supplementary information provided by Lena Höglund and Wilfried Winiwarter. Nonetheless they bear no responsibility for the use we made of this information and how it is translated into mitigation options in the CAPRI model.

matter, net energy, protein, and fibre for each animal (Pérez Dominguez, 2006; Leip et al., 2010). Furthermore, policy restrictions, including emission targets, as used in this impact analysis, may also influence decision making.

Agricultural GHG emissions are affected by the amount and intensity of animal or plant production. In CAPRI, emissions are calculated according to the IPCC Tier 2 method for the most important drivers (in particular cattle-related emissions). In previous CAPRI versions, technical methods of GHG emissions reduction have been largely neglected (with some exceptions). In this study, the description of technical mitigation options in the GAINS model has been tapped in a selected form. In particular, the mitigation potential (in the form of expected upper bounds for implementation), the costs and the current implementation rates of certain mitigation technologies in the reference scenario have been adopted.

Formal model set up

The regional income maximisation may be formulated as follows:

$$\begin{aligned}
&\max R(act) - C^T(act, fert, feed, mshar) \\
&s.t. \\
&G(act, feed, fert) \le 0 \\
&act_{idle} = mshar_{crop,idle,N2Ohis} \cdot HIST \\
&0 \le mshar_{a,m,e} \le 1, \forall m \\
&\textstyle\sum_m mshar_{a,m,e} = 1
\end{aligned} \tag{1}$$

where the regional indices are omitted and

- R revenue function, combining sales from marketable outputs from production activities as well as premiums directly paid to activities
- C^T total cost function, combining cost elements directly related to activities, as well as purchases of marketable inputs (feed, fertilizer), and costs of mitigation efforts
- G Vector constraint function representing agricultural technology
- act vector of production activities with a certain intensity. Typical element: act_a.
- a set of production activities (e.g., dairy cows with high yield)
- $fert$ vector of mineral fertilizer purchases. Typical element: $fert_n$
- n set of plant nutrients (N, P, K)
- $feed$ matrix of feed input coefficients. Typical element: $feed_{a,f}$
- f set of feed items (e.g., feed cereals)
- $mshar$ vector of mitigation shares. Typical element $mshar_{a,m,e}$
- m set of mitigation technologies (including “no mitigation”)
- e set of emission types (e.g., CH_4 from manure management)
- $idle$ idling activity for histosol land
- $HIST$ histosol land

The cost function is assumed to be separable into parts related to mitigation efforts and other costs:

$$\begin{aligned}
C^T(act, fert, feed, mshar) = &\textstyle\sum_a act_a \sum_{m,e} C^m(mshar_{a,m,e}) + fert_N \sum_m C^m(mshar_{N,m,N2O\min}) \\
&+ C^O(act, fert, feed)
\end{aligned} \tag{2}$$

where

- C^m mitigation cost per activity level for mitigation option m, which depends on mitigation share $mshar_{a,m,e}$ for activity a, mitigation option m, and targeting emission type e.
- C^O other (non-mitigation) cost depending on activity levels, feed coefficients, and fertilizer quantities.

In the case of idling histosol land there is no additional cost beyond the opportunity cost of not using this land. The framework above involves an important simplification: the mitigation shares do not enter the constraint function G(.) nor the cost function C^O. In the case of anaerobic digestion (AD), a relevant mitigation technology targeting CH_4, this seems to be approximately correct, if we assume that the residues (containing the nitrogen and other plant nutrients from the manure and other feedstocks for AD) are returned to the soil without significant losses. The only effect of AD is then to reduce CH_4 emissions from manure and to generate income (negative cost C^m).

The assumption of no influence of mitigation on constraints and other costs is more questionable for some other measures. Cattle vaccination or rice field aeration to reduce methane emissions might also impact on yields or other input requirements. Any measures to reduce N_2O emissions from fertilizer application such as precision farming or improved timing of fertilization would also influence the overall nutrient balance in the crop sector. This simplification is acknowledged and will be removed in subsequent applications.

Most emission types are calculated as the product of emission factors per activity level (determined as a function of yields and other characteristics) and activity levels. For some of them, mitigation measures may reduce emissions according to a factor $mfac_{a,e}$ below the standard, uncontrolled amount (= 100%). Formally,

$$emi_e = \sum_a mfac_{a,e} \cdot \varepsilon_{a,e} \cdot act_a$$

$$\text{where} \qquad (3)$$

$$mfac_{a,e} = \sum_m \mu_{a,m,e} \cdot mshar_{a,m,e}$$

and

emi_e emissions of type e.

$\varepsilon_{a,e}$ uncontrolled emission factor for emission type e from activity a.

$\mu_{a,m,e}$ reduction factor for emission type e from activity a, if a certain mitigation technology m were fully implemented (which may be infeasible).

Emissions of N_2O from synthetic fertilizers are incorporated similarly with the total use of mineral fertilizer adopting the role of emissions causing activity.:

$$emi_{N2O\min} = mfac_{N,N2O\min} \cdot \varepsilon_{N,N2O\min e} \cdot fert_N$$

$$\text{where} \qquad (4)$$

$$mfac_{N,N2O\min} = \sum_m \mu_{N,m,N2O\min} \cdot mshar_{N,m,N2O\min}$$

Emissions from enteric fermentation per animal category are calculated according to IPCC Tier 2 methods from animal numbers, feed intake in gross energy, and a methane conversion factor. As feed intake is generally not available, CAPRI used to follow a methodology described by the IPCC (2006, Chapter 10) to estimate the intake from parameters characterising animal needs, such as weight, and milk yield. This permits to estimate net energy requirement, convert it into gross energy by using average digestibility, and finally apply the methane conversion factor. This methodology has been used in CAPRI since many years (Perez-Dominguez 2006, Leip et al 2010) and it also results in emission factors per animal activity like those in equation (3).

However, one of the contributions of our study is a straightforward but important modification of the “standard” Tier 2 approach. In the CAPRI model, unlike the situation in inventory calculations envisaged by IPCC (2006), feed intake and its composition are known model variables. Therefore it is possible to directly compute gross energy intake from the endogenous feed input coefficients and thereby capture the effects of endogenous changes in the feed mix on digestibility and emissions. Mitigation factors are applied as above, reflecting the saving of methane emissions if, for example, propionate precursors or vaccination are used.

$$emi_{CH4en} = \sum_a mfac_{a,CH4en} \cdot act_a \cdot \sum_f \varepsilon_{a,f,CH4en} \cdot feed_{a,f}$$

$$where \qquad (5)$$

$$mfac_{a,CH4en} = \sum_m \mu_{a,m,CH4en} \cdot mshar_{a,m,CH4en}$$

In summary, the objective of a CAPRI supply model is to maximise the net revenues as in equation (1), considering given parameters like product prices and CAP premiums as well as the costs for mitigation measures and other costs. The model finds an optimum of activities, mitigation technologies and feed use for a given emission target.

Specification of mitigation cost functions

The CAPRI supply models are nonlinear inter alia because the cost function C^O is nonlinear. It is so because CAPRI considers that there may be unobserved costs, known to farmers but not included in the accounting cost, which increase more than proportionally if a certain crop is expanded. A motivation may be bottlenecks of labour and machinery which are not covered explicitly in CAPRI, but potentially also risk premiums. Due to these nonlinear costs farmers will not suddenly and to a large extent switch from barley to maize even if net revenues of maize happen to increase beyond those of barley in some scenario.

For activity levels, the "responsiveness" may be expressed in terms of elasticities, giving the percentage increase in an activity level if the output price, for example, is increasing by 1 %. For mitigation measures, responsiveness has been captured in a different way because most observed mitigation shares are zero such that elasticities cannot be defined. Instead responsiveness is measured in terms of the increase in the mitigation share if a certain subsidy is granted for mitigation. For the cost function calibration, we consider the choice of the mitigation share for a single fixed activity where mitigation receives a subsidy S (which is zero in the observed situation). The problem is thus to minimise net cost N:

$$\min_{mshar} N(mshar_{a,m,e}) = C^m(mshar_{a,m,e}) - S_{a,m,e} \cdot mshar_{a,m,e} \qquad (6)$$

where

S subsidy for implementation of the mitigation option mshar.

N net cost function, equal to cost net of the subsidy

The proposed specification splits the mitigation cost function C(.) into a part observed in GAINS and an unobserved part:

$$C^m(mshar_{a,m,e}) = (\kappa_{a,m,e} + \beta_{a,m,e}) \cdot mshar_{a,m,e} + 0.5\gamma_{a,m,e} \cdot (mshar_{a,m,e})^2 \qquad (7)$$

where

$\kappa_{a,m,e}$ Cost per activity level for a full implementation of a certain mitigation option as given in the GAINS database

$\beta_{a,m,e}$, $\gamma_{a,m,e}$ unobserved parameters

To specify the unknown parameters we use two conditions, the first one being the first order condition for cost minimisation at the observed mitigation share (assumed > 0 here, the case of zero initial shares is discussed below:

$$\partial C^m(mshar^0_{a,m,e}) / \partial mshar^0_{a,m,e} = 0 \qquad (8)$$

$mshar^0_{a,m,e}$ Current mitigation share according to the GAINS database

The second condition is an assumption related to responsiveness. For a certain subsidy S the optimal solution to (6) would be the implementation of mitigation up to the technical limit:

$$mshar^{1}_{a,m,e} = mshar^{\max}_{a,m,e} \tag{9}$$

We assume for the time being that at a relative subsidy of $s^{1}_{a,m,e}$ = 80% of the accounting costs from GAINS $\kappa_{a,m,e}$ the implementation would be just at its maximum. This assumption renders responsiveness explicit. If the percentage were only 10%, this would mean that farmers would quickly adopt this technology completely, because some unobserved benefits render this mitigation technology almost profitable also for the "late followers". If the percentage would be higher, say >100%, this would mean that for the "late followers" there are near zero unobserved benefits. By definition then, the first order condition for minimisation of the net cost *N(.)* should be zero at the maximum implementation share

$$\partial N^{m}(mshar^{1}_{a,m,e}) \big/ \partial mshar^{1}_{a,m,e} = \kappa_{a,m,e} + \beta_{a,m,e} + \gamma_{a,m,e} \cdot mshar^{1}_{a,m,e} - s_{a,m,e} \cdot \kappa_{a,m,e} = 0 \tag{10}$$

This is the second condition needed to specify a nonlinear cost function with smooth behaviour of the mitigation options.

Coming back to the typical case of zero initially observed mitigation shares, it may be concluded that there were insufficient unobserved benefits to farmers to render implementation attractive, even for the "early adopters". In this case it has been assumed that a relative subsidy of $s^{0}_{a,m,e}$ = 50% of the accounting costs from GAINS would be needed to render the option almost attractive for the first adopter such that the first order condition (8) holds with equality at a zero implementation share. Furthermore, as options with observed zero shares are apparently less attractive to farmers, a full implementation also by "late followers" may only be expected at a higher subsidy rate. Our assumption was 150% (rather than 80%) in this case, implying that "late followers" have even unobserved disutility from this mitigation option that needs to be overcome to achieve full implementation by all farmers. Some aspects of this modelling approach have to be stressed.

Responsiveness is specified according to plausible assumptions on the results of hypothetical scenarios, the introduction of a specific subsidy for one mitigation option only. This is conceptually not very different from the information in an elasticity matrix, giving the response of some agent if one price is changing and all others constant. The difference to the elasticity case and a weakness of our approach here is the lack of econometric evidence to specify the threshold values for the relative subsidies. However, such evidence is difficult to come by when considering the nature of future mitigation options.

Even though the approach may have a weak empirical basis, the alternative to set all unobserved parameters to zero is known to be further away from reality. It would imply, for example, that farmers are homogeneous in a region and would happily switch from one economic option to the next if the latter increases regional income by one Euro. Such jumpiness contradicts all anecdotal evidence.

3. Specification and major results of the simulation scenarios

A reference scenario (REF) and two mitigation policy scenarios have been constructed to highlight the importance of technological GHG emission mitigation options for achieving mitigation targets. The above mentioned specific technological mitigation options are available for the farmers to be voluntarily applied (in case they are needed to meet the 20% GHG reduction) in one scenario (HOM20-tech) while in the other scenario they are kept at zero or baseline level (HOM20). The latter case represents a scenario where GHG reductions would have to come mainly from agricultural activity changes, and as such also represents how CAPRI would have achieved reductions before improvement of the model.

The REF scenario assumes status quo policy as scheduled in the current legislation based on the information available at the end of August 2013. Thus the new Common Agricultural Policy (CAP) with the four basic regulations formally adopted by the Council of EU Agriculture Ministers in December 2013 are not considered as the EU Member States still have to decide on concrete detailed policy implementation until summer 2014. Furthermore, no specific GHG emission reduction requirements for the agricultural sector are implemented in REF.

The mitigation policy scenarios (HOM20 and HOM20-tech) aim at an EU-27 wide GHG emission reduction of 20% in the year 2030 compared to EU-27 emissions in the year 2005. For these mitigation policy scenarios we assume a specific Emission Trading Scheme only for Agriculture in the EU. The emission reduction obligations are set per Member State (MS) and NUTS2 region by implementing regionally homogeneous emission caps. Tradable emission permits are allocated to agricultural producers (1 permit equals 1 ton of CO_2 equivalent, where CH_4 and N_2O emissions from agricultural sources are considered). The agricultural producers can decide to use the permits in order to emit GHG or they can trade them with other agricultural producers. Trade of emission permits is allowed between regions (i.e. Nuts 2 level) within MS and at EU-27 wide level.[2]

It has to be stressed that the purpose of this paper is not to assess the impact of specific mitigation policies, but to show what difference it makes if technological mitigation options are available in the model to comply with emission abatement targets in the agricultural sector. Therefore the practicability of the policy scenario we chose is not of real importance, rather it is the difference in the results between the scenario with and the scenario without technological mitigation options.

Changes in agricultural GHG emissions per EU Member State

Table 2 presents a decomposition of the overall agricultural GHG emissions developments in the scenarios. The technological GHG mitigation options mentioned above are kept at zero or baseline level in the REF and HOM20 scenarios, while in the HOM20-tech scenario their application can be voluntarily increased by farmers. The REF scenario indicates the development of GHG emissions with no specific emission reduction requirements for agriculture in place, and shows the relative difference in emission levels between the projection year 2030 and the base year 2005. The policy scenarios show the policy effect of implementing a 20% non-GHG reduction obligation without (HOM20) and with (HOM20-tech) the possibility to increase the application of technological mitigation options. In the HOM20 scenarios we depict the relative change compared to the REF scenario in the year 2030.

Projection results of the REF scenario show an overall reduction in agricultural GHG emissions for the EU-27 of 0.3% in the year 2030 compared to the year 2005. However, projection results in the REF are quite diverse between the MS, and while some MS show a decrease in emissions, others are projected to have an increase. In the EU-15, results show a decrease of 0.5%, with highest reductions projected for Greece (-11.6%) and Italy (-4.8%), whereas eight countries show an increase in emissions, with the highest increases indicated for Portugal (+15.4) and Austria (+8.8%). For the EU-N12 an increase of 0.9% is projected, with eight countries increasing their emissions (some countries quite remarkably). Most

[2] For more information on the scenario setting please see Pérez Dominguez et al., 2012.

pronounced increases are predicted for Bulgaria and Latvia (+20.5% and +20.3%, respectively) and highest decreases for Romania and Hungary (-11.9% and -4.9%, respectively).

The emission reductions at MS level in the HOM20 scenarios have to be seen in the context of the individual MS emissions in the REF scenario and the emission reduction obligation of 20% the MS is faced with according to the policy. Furthermore, the changes in agricultural GHG emissions per EU MS as indicated in Table 2 show if a MS is a net seller or net buyer of GHG emission permits. For example, Austria is projected to increase its agricultural GHG emissions by 8.8% by 2030 compared to 2005 in the REF scenario. In the HOM20 scenarios, Austria would have to reduce its emissions by 20% compared to 2005. This is equivalent to 28.8 percentage points compared to REF. As Austria is projected to decrease emissions by 16.1% in HOM20 compared to REF, this indicates that Austria would be a net buyer of agricultural emission permits in this policy scenario. As can be seen in Table 2, the effect of the availability of technological mitigation options on overall GHG mitigation in the MS varies between the MS. In some countries, like e.g. Austria, this leads to a further increase in total GHG mitigation and thus a reduced need to buy agricultural emission permits, while in other MS, like e.g. Ireland this leads to a reduced overall GHG mitigation and thus less selling of agricultural emission permits.

Table 2. Changes in agricultural GHG emissions per EU Member State in 2030

	2005	**REF**	**HOM20**	**HOM20-tech**
	[1000t]	% difference to 2005	% difference to REF	
EU-27	400965	-0.3	-20.2	-20.2
Austria	7461	8.8	-16.1	-16.8
Belgium-Lux	9354	2.2	-15.3	-19.5
Denmark	9747	-0.8	-11.4	-18.8
Finland	7284	5.9	-31.0	-34.6
France	74366	-4.2	-15.9	-21.5
Germany	61139	-2.1	-17.1	-20.0
Greece	5945	-11.6	-11.8	-12.2
Ireland	21298	4.5	-34.7	-30.1
Italy	28216	-4.8	-8.1	-12.0
Netherlands	17216	5.6	-17.1	-21.6
Portugal	5048	15.4	-26.5	-16.3
Spain	31009	7.1	-24.9	-15.1
Sweden	6909	4.1	-19.0	-20.0
UK	45654	-3.8	-35.3	-21.3
EU-15	330647	-0.5	-20.7	-20.1
Bulgaria	3969	20.5	-18.4	-19.1
Cyprus	397	7.3	-9.8	-14.3
Czech Republic	6096	2.5	-17.7	-18.4
Estonia	1232	5.0	-37.5	-27.7
Hungary	7249	-4.9	-14.3	-20.4
Latvia	1799	20.3	-31.0	-15.5
Lithuania	3681	12.8	-25.2	-24.0
Malta	67	12.5	-7.8	-8.4
Poland	27185	3.8	-17.3	-22.9
Romania	14995	-11.9	-16.0	-15.7
Slovak Republic	2335	-4.3	-9.1	-18.2
Slovenia	1311	-2.9	-13.9	-24.9
EU-12	70318	0.9	-17.7	-20.4

Impact on agricultural activity levels

Table 3 presents how agricultural activities in the EU-27 are affected in the scenarios HOM20 and HOM20-tech compared to REF. The impacts in HOM20-tech are less than half of the impact recorded in the HOM20 scenario. This means that the available technological mitigation options can potentially reduce the cuts in herd size and agricultural area provoked by the implemented policy of a 20% GHG emission reduction by more than half. The largest difference in terms of production is reported for beef meat activities, with a reduction in herd size of 43.3% without technology options and 15.7% with technologies. Changes in supply are smaller -23.5% (HOM20) and -8.3 % (with HOM20-tech).

Large differences can be observed between the activities. Dairy cows and pig fattening for example are much less affected than beef meat activities The main reason is that reductions in the first two activities would entail relatively higher economic losses per unit of emission savings. For most of the activities, the production decline is smaller than the reduction in hectares or herd size, which indicates an 'intensification' of the agricultural activities. As the pure beef herd is decreasing significantly more than the dairy herd, a structural change in the herd structure can be expected, using more the offspring of the dairy herd for meat production.

Table 3. Change in area, herd size and supply for the EU-27 for activity aggregates

	REF		HOM20		HOM20-tech	
	Hectares or herd size	Supply	Hectares or herd size	Supply	Hectares or herd size	Supply
	[1000 ha or hds]	[1000 t, 1000 ha]	% difference to REF			
Utilized agricultural area	181,693	na	-10.3	na	-1.7	na
Cereals	52,856	320,148	-8.5	-6.7	-2.8	-2.0
Oilseeds	11,856	34,291	-7.3	-7.4	-2.6	-2.8
Other arable crops	5,783	164,261	-2.3	na	-1.2	na
Vegetables and Permanent crops	25,060	130,747	0.1	na	0.0	na
Fodder activities	77,391	33,378	-21.5	-18.8	-6.2	-5.1
Set aside and fallow land	8,746	Na	39.3	na	40.9	na
Dairy cows	21,722	160,509	-6.9	-5.9	-2.2	-1.9
Beef meat activities	18,213	7,992*	-43.3	-23.5	-15.7	-8.3
Pig fattening	252,970	23,494	-5.9	-6.0	-2.4	-2.5
Pig breeding	15,037	259,528	-6.3	-5.9	-2.6	-2.4
Milk Ewes and Goat	74,090	5,141	-21.3	-12.3	-7.6	-4.9
Sheep and Goat fattening	48,548	742	-21.2	-20.2	-7.2	-6.6
Laying hens	459	7,776	-2.0	-1.7	-0.8	-0.8
Poultry fattening	6,703	13,518	-3.4	-3.1	-1.4	-1.3

Note: na = not applicable;*total beef supply includes beef from suckler cows, heifers, bulls, dairy cows and calves

The changes in beef herd size and production at MS level are presented in Table 4. The table perfectly exemplifies how remarkably the scenario results are amplified by the availability of technological mitigation options with regard to the impact of the mitigation obligation on beef meat activity levels. It can be seen that due to the technological mitigation options the impact on activity levels is by and large only a third of the impact than in the HOM20 scenario.

Table 4. Change in beef herd size and production per EU Member State

	REF		HOM20		HOM20-tech	
	Herd size	Prod.	Herd	Prod.	Herd	Prod.
	1000 hds	1000 t	% difference to REF			
EU-27	18,213	7,992	-43.3	-23.5	-15.7	-8.3
Austria	410	205	-31.7	-19.5	-11.4	-7.1
Belgium-Lux	521	285	-27.8	-18.8	-9.2	-6.3
Denmark	132	125	-55.1	-20.9	-21.8	-7.8
Finland	149	81	-48.5	-23.6	-20.7	-9.5
France	4,923	1,688	-32.4	-20.9	-10.8	-7.0
Germany	1,288	1,048	-41.3	-25.1	-14.7	-9.1
Greece	194	58	-46.8	-12.6	-13.5	-3.9
Ireland	2,047	619	-52.8	-32.3	-16.9	-9.0
Italy	1,150	755	-12.1	-9.2	-4.9	-3.7
Netherlands	143	380	-34.9	-23.5	-8.0	-7.4
Portugal	458	122	-48.5	-18.9	-20.0	-7.8
Spain	2,191	641	-60.9	-23.2	-23.0	-9.2
Sweden	334	152	-42.1	-25.3	-15.7	-9.4
UK	3,203	1,007	-57.5	-37.7	-21.3	-13.8
EU-15	17,144	7,166	-43.4	-23.9	-15.4	-8.3
Bulgaria	46	30	-68.8	-17.9	-24.0	-7.2
Cyprus	2	4	-11.8	-1.0	-5.4	-0.7
Czech Republic	157	72	-62.4	-28.5	-40.5	-14.0
Estonia	19	19	-43.1	-26.7	-14.4	-8.9
Hungary	45	33	-47.4	-15.6	-26.4	-7.2
Latvia	12	21	-40.3	-29.5	-17.1	-12.4
Lithuania	33	40	-53.3	-29.2	-17.8	-10.1
Malta	3	2	-14.6	-11.4	-7.1	-5.7
Poland	473	396	-26.8	-20.9	-11.2	-8.5
Romania	92	134	-46.4	-18.9	-13.6	-5.6
Slovak Republic	38	26	-29.6	-5.4	-8.9	-1.7
Slovenia	149	48	-51.6	-14.8	-26.2	-6.8
EU-12	1,069	826	-41.1	-20.7	-19.2	-8.2

Impact on EU imports, exports and net trade position

The changes in EU imports, exports and net trade position for aggregate activities are presented in Table 5. Taking into account the production drop in the EU, the trade balance is expected to worsen for almost all agricultural products due to the inelastic demand and loss of EU competitiveness. The exception is oil cakes, which is due to lower feed demand from the EU livestock sector. In line with the production developments, changes in EU imports and exports are more pronounced in the livestock than in the crop sector. Again, the technological mitigation options clearly soften the negative effects on the trade balance for all agricultural products. The impact on imports drops to one third or lower in percentage points compared to a situation without these options. On the export side, the impact is less pronounced but still significant.

Table 5. Change in EU imports, exports and net trade position for aggregate activities according to the HOM20 and HOM20-tech scenario

	REF			HOM20			HOM20-tech		
	Imports	Exports	Net trade position	Imports	Exports	Net trade position	Imports	Exports	Net trade position
	1000 t			% diff to REF		1000 t	% diff to REF		1000 t
Cereals	10,667	47,415	36,749	83.0	-22.7	17,135	28.6	-9.2	29,334
Oilseeds	25,093	10,663	-14,430	8.0	-9.3	-17,432	3.3	-3.2	-15,587
Other arable field crops	2,047	3,748	1,701	-1.3	-6.0	1,503	-2.5	-1.7	1,687
Veg. and Permanent crops	25,983	7,395	-18,588	2.1	-1.6	-19,245	0.8	-0.8	-18,853
Oils	10,862	3,840	-7,023	1.3	-5.9	-7,396	0.3	-2.2	-7,146
Oil cakes	23,152	3,325	-19,827	-11.9	8.2	-16,790	-7.3	4.2	-17,997
Beef	552	137	-414	235.9	-93.5	-1,844	64.3	-62.1	-855
Pork meat	6	2,278	2,272	222.0	-51.5	1,085	64.4	-21.7	1,774
Sheep and goat meat	277	20	-257	62.8	-72.5	-445	15.2	-53.4	-310
Poultry meat	288	1,296	1,008	88.8	-27.5	396	27.8	-11.7	777
Dairy products	497	2,924	2,427	41.7	-20.0	1,637	9.9	-7.2	2,167

Impact on EU producer and consumer prices

As outlined above, the production decreases in the EU-27 are not compensated by equivalent imports. As a consequence all producer and consumer prices in the EU are projected to increase (Table 6). The increases in producer prices are in line with the observed production decreases in the HOM scenarios, and reflect that price increases are highest for beef and milk. Consumer price changes are in the same magnitude when looking at absolute changes, but due to high consumer margins (assumed constant) the relative changes are much lower for them. Clearly, the more GHG intensive products (e.g. beef) face higher price increases, reflecting the internalization of climate impacts in consumer behaviour. The relative increases in consumer prices for meat and dairy products vary between 0.2% and 22% in HOM20 and only between 0.1% and 7.7% in HOM20-tech.

Table 6. Change in producer and consumer price for selected products

	Producer price			Consumer price		
	REF	HOM20	HOM20-tech	REF	HOM20	HOM20-tech
	EUR/t	% difference to REF		EUR/t	% difference to REF	
Cereals	250.9	12.3	4.7	3,514.6	0.9	0.3
Oilseeds	301.3	15.8	5.5	3,965.2	1.0	0.4
Other arable field crops	124.2	5.8	2.5	1,295.5	0.5	0.2
Vegetable and Permanent crops	868.7	2.1	0.8	2,368.2	0.2	0.1
Beef	5,984.0	48.2	16.2	11,881	22.1	7.7
Pork meat	2,393.8	24.9	8.9	7,483.1	8.2	3.0
Sheep and goat meat	8,563.5	27.4	13.0	13,940.7	10.6	5.6
Poultry meat	2,131.3	11.0	4.1	4,810.7	6.6	2.5
Cow and buffalo milk	404.4	43.7	14.2	na	na	na
Sheep and goat milk	841.8	30.1	10.2	na	na	na
Eggs	1,595.2	12.0	4.6	4,399.0	4.3	1.7

Impact on agricultural income

Following the decrease in EU production, which is not fully compensated by equal imports to meet the new demand, and the resulting increase in producer prices, total agricultural income in the EU-27 is projected to increase by 6.7%. The income losses due to decreased production and increasing costs are offset by higher producer prices. Almost all regions in EU-27 experience a positive total income effect. The percentage income increase in the EU-15 is slightly lower (+6.6 %) than in the EU-N12 (+7.5%). However, the aggregated result hides large differences between the regions of EU-27, as can be observed in figure 1.

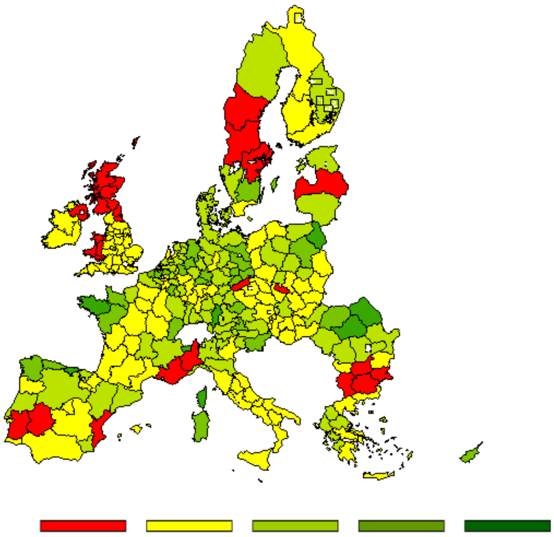

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Figure 1. Impact on total agricultural income, HOM20-tech (% change relative to REF)

4. Concluding remarks

In previous GHG mitigation policy analyses with the CAPRI model technological mitigation options (i.e. technical and management-based GHG mitigation measures) were not endogenously implemented in the CAPRI model. For this study, the general calculation of GHG emission inventories in the CAPRI model has been further improved, and specific endogenous GHG mitigation technologies have been introduced to the CAPRI model, translating most of the reduction measures that are also used in the GAINS model (2013) into the CAPRI model set-up. We employ the new CAPRI model version to run a reference scenario and to assess the impact of a GHG emission mitigation policy reflecting a homogeneous GHG emission reduction target with the possibility of trading emission permits at MS level and NUTS2 level. The mitigation target is an EU-27 wide GHG emission reduction of 20% in the year 2030 compared to EU-27 emissions in the year 2005. Two alternative scenario settings are presented to illustrate the operation of the model: one with the availability of technological mitigation options and one without.

The modelled mitigation policy shows important impacts on agricultural production in the EU-27, especially for cattle and fodder production. Total agricultural income is projected to increase at EU level by 6.7% in the scenarios with the availability of technological mitigation options, but important regional differences exist, and a few regions may have negative income impacts. The increase in income is mainly due to the higher producer prices, which can offset the loss in production and increasing costs in more than 90% of the EU regions (which leads to increases in agricultural income). In this context it is important to note that the higher producer prices are reached under a specific set of assumptions, especially with respect to the EU border protection mechanisms and levels in place in 2030. Consumers, on the contrary, will have to pay a higher price for food, especially for meat and dairy products (up to 22%). It also has to be kept in mind that it is likely that some farmers might have to leave the sector in case they are not able to cope with the GHG mitigation obligations. Obviously, only farmers remaining in the sector would benefit from the projected increase in total agricultural income.

The results indicate clearly that the negative impact on agricultural production and trade can be reduced to roughly one third when mitigation options are available to farmers. There is quite some uncertainty if by 2030 more or less mitigation options than used in our scenarios will be technically available to and effectively be implemented by farmers. As our analysis shows, different assumptions about the availability and uptake of technologies may alter the outcome significantly. This is a strong signal for enhanced research and development in the area of technological mitigation options, as well as policies that promote their diffusion.

It has to be noted that (i) the genetic breeding option is so far not considered in the CAPRI model and (ii) the share of livestock production able to apply the considered technology options is sometimes very limited and country specific, basically reflecting the share of farms large enough to implement such technologies (GAINS, 2013). Assuming a wider applicability, say due to additional farm structure change or accelerated technological maturation, mitigation options in the animal sector might become more important. On the other hand, almost 100% of EU crop sector would potentially use the provided mitigation options.

With respect to global GHG emissions reduction, it has to be kept in mind that, even though the EU meets emission reductions of 20% in the agriculture sector in our policy scenarios, the projected increase in EU imports go along with an increase of production outside the EU and the net gain for global GHG emissions reduction would depend significantly on the relative GHG efficiency of agriculture in the exporting country compared to the EU. Again, if more technological mitigation options would be available, this would also reduce any potential emission leakage effect.

Our analysis does not take into account support measures that might be introduced in order to help farmers adjusting to the new policy framework. In this respect it might, for example, be useful to consider the implementation of subsidy schemes in future modelling exercises.

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