TOWARDS SUSTAINABLE AGRI-FOOD SYSTEMS:
BALANCING BETWEEN MARKETS AND SOCIETY

Assessing impacts of activating the technological emission mitigation potential of EU agriculture

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Abstract

We present a further developed CAPRI modelling approach for technological (i.e. technical and management-based) greenhouse gas emission mitigation options. The model is employed to assess the potential of mitigation technologies in EU agriculture by 2030, and how their application could impact agricultural market and emission developments. Scenario results show that without incentives the uptake of the considered technologies is very limited. Setting a 15% emission reduction obligation for EU agriculture is an incentive that triggers technology adoption. Once technology uptake is subsidised, their share in mitigation increases substantially, which considerably decreases any adverse effects on EU production and emission leakage. The results underline the importance of activating and supporting the uptake of mitigation technologies in order to effectively increase agriculture's contribution to emission mitigation in the EU.

Keywords: EU agriculture, emissions, mitigation, technologies

1 Introduction

The Paris Agreement on Climate Change legally entered into force on 4 November 2016, but specific modalities and procedures still have to be negotiated. Similarly, the parties that ratified the agreement have to decide how they turn their Intended Nationally Determined Contributions (INDCs) into Nationally Determined Contributions (NDCs). This also holds for the European Union (EU), which submitted the European Council's agreement on domestic climate and energy goals for 2030 as INDC (Council of the European Union, 2014). Although the EU and its Member States still have to fine-tune how the greenhouse gas (GHG) emission reduction targets should be achieved, in the latest impact assessment accompanying the European Commission's proposal for a new Effort Sharing Decision, which covers also emissions from the agriculture sector, it is acknowledged that the mitigation potential for agriculture in the EU might be rather limited (European Commission, 2016a,b).

Considering that agriculture is an important emitter of non-CO_2 emissions, namely methane and nitrous oxide, contributing about 10% to total EU GHG emissions[1], we want to further enhance the discussion on agriculture's possible contribution to emission mitigation in the EU. Therefore we specifically have a closer look on the potential of technological (i.e. technical and management-based) GHG mitigation options for EU agriculture, how their application might have to be activated, and how this could impact both agricultural market and emission developments. For the analysis we use the CAPRI modelling system, which was recently enhanced to account endogenously for a few mitigation technologies in policy scenario analyses (Van Doorslaer et al., 2015). We further developed the CAPRI modelling system by including a larger selection of technological mitigation options and improving the respective modelling approach.[2]

When looking at the potential of technological mitigation options it is particularly important to keep farmers behaviour regarding technology adoption in mind. The examination of factors influencing the adoption of technologies and management practices has been a focus of agricultural economics research for a long time (e.g., Sunding and Zilberman, 2001; Knowler and Bradshaw, 2007; OECD, 2012). Griliches (1957) was one of the first economists to analyse the adoption and diffusion of technological innovations in agriculture from an economic perspective, and he found that profitability was the largest determinant for the adoption of hybrid maize. Although many other

[1] In this paper we focus only on the agricultural non-CO_2 emissions methane and nitrous oxide, i.e. CO_2 emissions (and removals) from land use, land-use change, and forestry (LULUCF) as well as other CO_2 emissions related to energy consumption at farm level (e.g., in buildings and machinery use) or to the processing of inputs (e.g., mineral fertilizers) are not considered.

[2] This paper is based on model developments and scenarios developed in the project ‘Economic assessment of GHG mitigation policy options for EU agriculture’ (EcAMPA 2). For more information on the project and further scenarios, see Pérez Domínguez et al. (2016).

studies confirm that profitability and profit maximisation are (some of) the most important drivers for the adoption of a certain production technology, the vast majority of the literature also points to various other characteristics that determine whether or not a technology is adopted by farmers. These other factors comprise mainly issues like uncertainty and risk involved in changing a management practice, farm size, simplicity and flexibility of the technology, as well as age, education and experience of the farmer (see e.g. McGregor et al., 1996; Barr and Cary, 2000; and the reviews in Marra et al., 2003; Knowler and Bradshaw, 2007; Prokopy et al., 2008; OECD, 2012; Pierpaoli et al., 2013; Sanchez et al., 2016; Wreford et al., 2017). Such non-economic factors are often neglected in studies indicating would-be win–win mitigation measures (i.e. measures that are supposed to reduce GHG emissions and save costs at the same time) in the agricultural sector (Moran et al., 2013). In our modelling approach we therefore specifically try to consider the influence of non-economic factors in terms of technology uptake.

2 Modelling approach and scenario setup

CAPRI (Common Agricultural Policy Regional Impact Analysis) is a global economic large-scale, comparative-static agricultural sector model. The model focuses on the EU (at regional, Member State and aggregated EU-28 levels), but it is a global model as it covers global bilateral trade of major agricultural commodities 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 models combine a Leontief technology for intermediate inputs covering low- and high-yield variants for the different production activities, with a non-linear cost function that captures the effects of labour and capital on farmers' decisions. In addition, constraints relating to land availability, animal requirements, crop nutrient needs and policy restrictions (e.g. production quotas) are taken into account. The cost function used allows for calibration of the regional supply models and a smooth simulation response. The market module consists of a spatial, global multi-commodity model for about 60 primary and processed agricultural products, covering 77 countries in 40 trading blocks. Bilateral trade flows and attached price transmission are modelled based on the Armington assumption of quality differentiation. Supply, feed, processing and human consumption functions in the market module ensure full compliance with micro economic theory. The link between the supply and market modules is based on an iterative procedure. One of the strengths of CAPRI is that it simulates policy impacts for the EU at Member States and NUTS 2 level, while at the same time global world trade of agricultural products is consistently modelled. This interaction between EU and global markets allows to capture global price feedback of the simulated policies (Britz and Witzke, 2014).

CAPRI captures the links between agricultural production activities in detail (e.g. food/feed supply and demand interactions or animal production 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. With this information, CAPRI is able to calculate GHG emission coefficients following the IPCC guidelines (IPCC, 2006), using generally a Tier 2 approach for the calculation of emissions. For activities for which the necessary underlying information is missing, a Tier 1 approach is used (e.g. rice cultivation). It has to be mentioned that the CAPRI calculation of emissions is not homogenous between the EU and the rest of the world. While the emissions of EU agriculture are calculated directly based on specific agricultural activities (i.e. emissions per animal and per ha) in the CAPRI supply model, GHG emissions for the rest of the world are estimated on a commodity basis (i.e. per kg of product) in the market model of CAPRI. For the EU, the underlying supply model incorporates technological change (e.g. growth in yields, allocation of new technologies), which allows emission factors to change over the projection period. To allow for emission intensity changes over time also in non-EU countries, trend functions are estimated for the emission intensities in the rest of the world using IPCC Tier 1 coefficients as prior information within a robust Bayesian estimation framework, combining data on production quantities and emission inventories from FAOSTAT (see e.g. Barreiro-Hurle et al., 2016). A detailed description of the general calculation of agricultural emission inventories in CAPRI is given in Pérez Domínguez (2006), Leip et al. (2010), and Pérez Domínguez et al. (2012; 2016).

The CAPRI model was only recently enhanced to account endogenously for a few technological (i.e., technical and management-based) mitigation options in policy scenario analysis (Van Doorslaer et al., 2015; Fellmann et al., 2017). The approach was now further developed and more technological options have been included into the CAPRI model. For this paper the following 12 mitigation technologies are specifically considered for EU agriculture (a detailed description of each mitigation option is given in Pérez Domínguez et al., 2016):

- Livestock: Anaerobic digestion at farm scale, Low nitrogen feed, Linseed as feed additive, Breeding programs to increase (i) milk yields of dairy cows and (ii) ruminant feed efficiency.
- Crops: Precision farming, Variable Rate Technology, Better timing of fertilization, Nitrification inhibitors, Rice measures, Fallowing histosols (organic soils), Increasing legume share on temporary grassland.

For the underlying assumptions regarding implementation costs, potential revenues, cost savings and initial mitigation potential per technological option we mainly rely on GAINS data from 2013 (GAINS, 2013; Höglund-Isaksson et al., 2013) and its updated version of 2015 (GAINS, 2015; Höglund-Isaksson et al., 2016), as well as on information collected within the AnimalChange project (Mottet et al., 2015). In the following we outline the methodology of modelling costs and uptake of mitigation technologies (see also Pérez Domínguez et al., 2016).

Methodology of modelling costs and uptake of mitigation technologies

The general modelling approach for the specification of cost functions in the CAPRI model is also used for the specification of costs involved in the adoption of a mitigation technology. CAPRI supply equations are non-linear because, inter alia, the cost function is non-linear. With this, CAPRI considers that there may be other costs, known to farmers but not included in the pure accounting cost statistics, which increase more than proportionally when production expands.[3] These other costs may be the result of bottlenecks of labour and machinery use, but potentially also to the existence of risk premiums (i.e. risk aversion behaviour by farmers) or rotation constraints. Owing to these non-linear costs, farmers will not suddenly switch from one commodity (e.g. barley) to another one (e.g. maize), even if net revenues of the second commodity happen to increase further. A sudden and large switch to the production of a more profitable commodity (e.g. maize instead of barley) would be the outcome of a linear programming model and depicts a problem known as ‘over-specialisation’. As this cannot be captured by statistics, CAPRI uses non-linear costs to reflect a rather smooth responsiveness by farmers to incentives that actually favour the switch to the production of a different commodity. These non-linear costs are known in the literature as ‘calibration costs’ and are a well-established and commonly used modelling approach (Howitt, 1995; Heckelei and Britz, 2005; Heckelei et al., 2012).

For commodity production, the ‘responsiveness’ to economic and political incentives is expressed in terms of (price–supply) elasticities, which illustrate the percentage increase in production of a commodity if the output price for that commodity increases by 1%. For technological mitigation measures, responsiveness cannot be captured with elasticities, because most rates of adoption of the mitigation technologies are zero in the base year and, therefore, elasticities cannot be defined. Instead, the responsiveness to applying a certain mitigation technology is measured in terms of the increase in the implementation share of this technology if a certain subsidy is granted for mitigation.

[3] This applies to the production of a certain commodity (e.g. maize) in a specific NUTS 2 region (e.g. Andalucía).

This is illustrated below with an example where we consider the choice of the mitigation (implementation) share for a single fixed activity, where a subsidy, S (which is zero in the observed situation), is paid for mitigation and there is potentially also secondary revenue, R (e.g. from energy produced in anaerobic digestion plants). Thus, the problem is to minimise net costs of adoption:

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

where

mshar vector of mitigation (implementation) shares

a set of production activities (e.g. dairy cows)

m set of mitigation technologies (including 'no mitigation')

e emission type (e.g. CH_4 from manure management)

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

C^m mitigation cost per activity level for mitigation option *m*, which depends on mitigation (implementation) share $mshar_{a,m,e}$ for activity *a*, mitigation option *m* and targeting emission type *e*

S subsidy for implementation of the mitigation option *mshar*.

R secondary revenue from implementation of the mitigation option *mshar*.

The specification used splits the CAPRI mitigation cost function, *C(.)*, into (1) a part coming from the cost database (i.e. GAINS and other sources) and (2) other costs not accounted for in that database. The latter are costs directly related to the determinants of technology adoption going beyond pure profitability considerations and are generally unknown (see introduction section on the (non-) adoption of technologies by farmers):

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

where

$\kappa_{a,m,e}$ cost per activity level for full implementation of a certain mitigation option as given in the cost database; emission type *e* from activity *a*, if a mitigation technology *m* is used

$\lambda_{a,m,e}$ parameter for non-constant accounting cost per activity level for full implementation of a certain mitigation option, *m*, for emission type *e* from activity *a* (typically 0)

$\beta_{a,m,e}$, $\gamma_{a,m,e}$ (additional) cost parameters not covered by the cost database.

C^m can be interpreted as the average mitigation cost function for each activity unit actually applying the technology (i.e. the costs for the technology per commodity to which we apply the measure). Generally, we would expect average costs to increase with higher mitigation shares, which means that first we assume that those farms adopt the measure for which adoption is less costly.

For the parameter specification, two cases have to be distinguished, depending on whether or not the mitigation technology is already applied in the base year. We first outline the parameter specification when the mitigation technology is already adopted in the base year (this case is represented in the left panel of Figure 1).

To specify the cost parameters that are not depicted in the cost database (i.e. the ones related to not purely economic determinants for technology adoption as outlined in the introduction), we use two conditions. The first condition is the first order condition for cost minimisation at the observed share of mitigation (assumed here to be >0; the case of an initial share of zero is discussed below):

$$\partial N(mshar^0_{a,m,e}) \big/ \partial mshar^0_{a,m,e} = \partial C^m(mshar^0_{a,m,e}) \big/ \partial mshar^0_{a,m,e} - S^0_{a,m,e} - R_{a,m,e} = 0$$

where

$mshar^0_{a,m,e}$ current mitigation share according to historic data (GAINS database), m0 in Figure 1.

The second condition is an assumption related to responsiveness, namely the specification of a non-linear cost function with smooth behaviour of uptake of the technological mitigation options. For a certain subsidy, *S*, the optimal solution would be the implementation of a mitigation technology up to the technical limit (which is given in the GAINS database):

$mshar^{1}_{a,m,e} = mshar^{\max}_{a,m,e}$ (m1 in Figure 1)

By definition then, the first order condition for minimisation of the net cost, *N*(.), should be zero at the maximum implementation share.

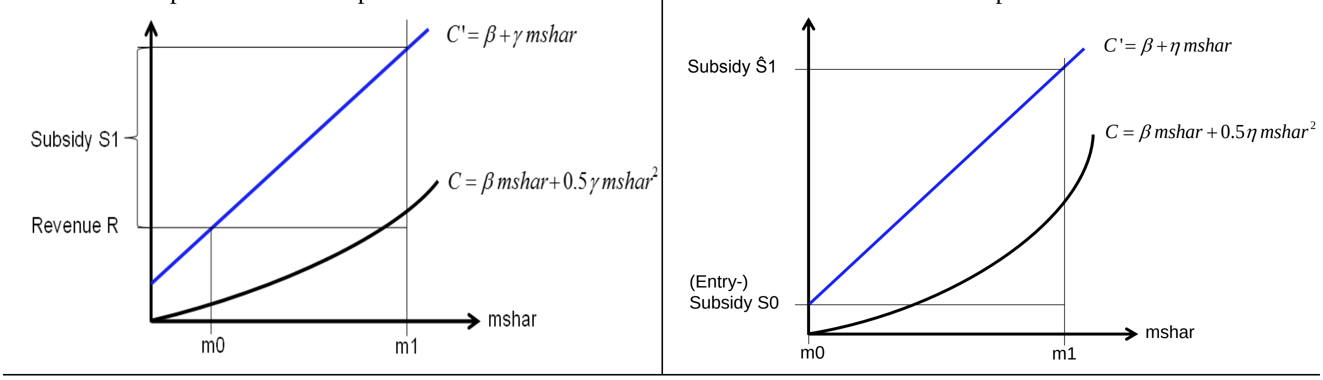
$$\frac{\partial N^{m}(mshar^{1}_{a,m,e})}{\partial mshar^{1}_{a,m,e}} = \kappa_{a,m,e} + \beta_{a,m,e} + \left(\lambda_{a,m,e} + \gamma_{a,m,e}\right) mshar^{1}_{a,m,e} - S^{1}_{a,m,e} - R_{a,m,e} = 0$$

We assume for the time being that the implementation of a mitigation technology would be at its maximum if a relative subsidy ($S^{1}_{a,m,e}$) of 80 % of the accounting costs from GAINS ($\kappa_{a,m,e}$) is paid. The assumption of 80 % explicitly allows for some responsiveness of the farming sector to financial incentives for applying the technology. If a lower relative subsidy would be assumed (e.g. only 10 %), this would mean that farmers would quickly adopt the technology completely. However, this would be unrealistic, following the determinants of technology adoption outlined in the previous section. If a higher relative subsidy would be assumed (e.g. >100 %), this would mean that, for those farmers that are 'late followers' of adopting the technology, there would be near zero benefits of applying the technology.

The parameter specification has to be done a bit differently when the mitigation technology is not adopted in the base year (see Figure 1, right panel). There are several technological mitigation options that, according to the GAINS database, are currently not applied by the farmers (i.e. the uptake of these technologies is zero in the base year). This holds particularly true for newly developed (or to be developed) technologies. Zero implementation implies that it is currently not attractive for farmers to apply the technology. To model the cases with zero uptake in the base year, we assume that a relative subsidy ($S^{0}_{a,m,e}$) of 20 % of the accounting costs would be needed to make the technology attractive for the first adopter. Furthermore, as the technological mitigation options with an observed uptake of zero in the base year are apparently less attractive to farmers, full implementation by 'late followers' may be expected only at a higher subsidy rate. Our assumption for these cases is 120 % (rather than the assumed 80 % for those technologies already applied in the base year), which implies that the uptake of the mitigation technology by 'late followers' is more heavily constrained by (some of) the non-economic determinants for technology adoption outlined in the introduction. Thus, we assume that a higher incentive is needed to achieve full adoption of the mitigation technology by all farmers. This case is represented in the right panel of Figure 1.

Figure 1: Representation of mitigation cost curves with and without initial implementation

Representation of mitigation cost curves with positive initial implementation	Representation of mitigation cost curves with zero initial implementation



Scenario setup

We construct one reference scenario and two mitigation policy scenarios. In all three scenarios the above mentioned 12 technological mitigation options are considered and can be applied by farmers.

The reference (REF) scenario incorporates agricultural and trade policies approved up to 2015. The measures of the CAP are covered, including measures of the latest 2014–2020 reform of the EU´s Common Agricultural Policy (CAP), including direct support measures implemented at Member

State or regional level and the abolition of the milk and sugar quota systems.[4] In general terms, the REF scenario is calibrated to the European Commission's medium-term prospects for EU agricultural markets and income (European Commission, 2014), and then extended to the projection year 2030 by using trends from external sources (e.g. information from the GLOBIOM model). The following targets are considered in the calibration: supply, demand, production, yields and prices. Furthermore, the REF scenario also incorporates assumptions on macroeconomic developments (like GDP growth, exchange rates, world oil prices, and population growth), again mainly relying on assumptions of the European Commission (2014). A detailed description and discussion of the CAPRI calibration process is given in Blanco Fonseca (2010) and Himics et al. (2014).

The simulated two GHG mitigation policy scenarios rely on the same assumptions as the REF scenario regarding macroeconomic drivers, and domestic and trade policies. However, in both policy scenarios we aim at a compulsory reduction of agriculture GHG emissions (i.e. only considering the non-CO_2 emissions of methane and nitrous oxide) in the EU-28 of 15% in 2030 compared with 2005. The 15% EU emission reduction target is translated into heterogeneous targets per Member State following a cost-effective allocation (ascertained in an auxiliary scenario via a carbon price[5]). One mitigation policy scenario (HET15) is without, whereas the other scenario (HET15sub) is with subsidies specifically paid for the adoption of the considered technological GHG mitigation options. The subsidy assumed covers 80% of the adoption costs for the voluntary adoption of technologies.

3 Scenario results

In the following we first present the scenario results with respect to impacts on emissions, production, prices, income, consumption, trade, and emission leakage. Then we have a closer look on the results with regard to the modelled mitigation technologies.

Figure 2 presents decomposition of EU agriculture GHG emission developments under the REF and policy scenarios in the projection year 2030. We compare the emissions in the REF scenario to historical emissions in 2005, whereas in the mitigation policy scenarios we want to depict the policy effect and therefore compare results in 2030 relative to the REF scenario. Results of the REF scenario show that, without any specific mitigation policy in place, agriculture GHG emissions in the aggregated EU are projected to decrease by about 2.3% by 2030 compared with 2005. Projection results are rather diverse across Member States, with 12 Member States showing increases in their agricultural emissions, while the other Member States show emission decreases. The highest increases are projected for Estonia (29%), Latvia (22%), Cyprus (14%), Portugal (12%) and Spain (9%). On the other hand, agricultural GHG emissions in the REF scenario decrease most in Malta (–25%), Italy (–16%), Romania (–13%), Belgium and Luxembourg (–13% each) and the United Kingdom (–10%).

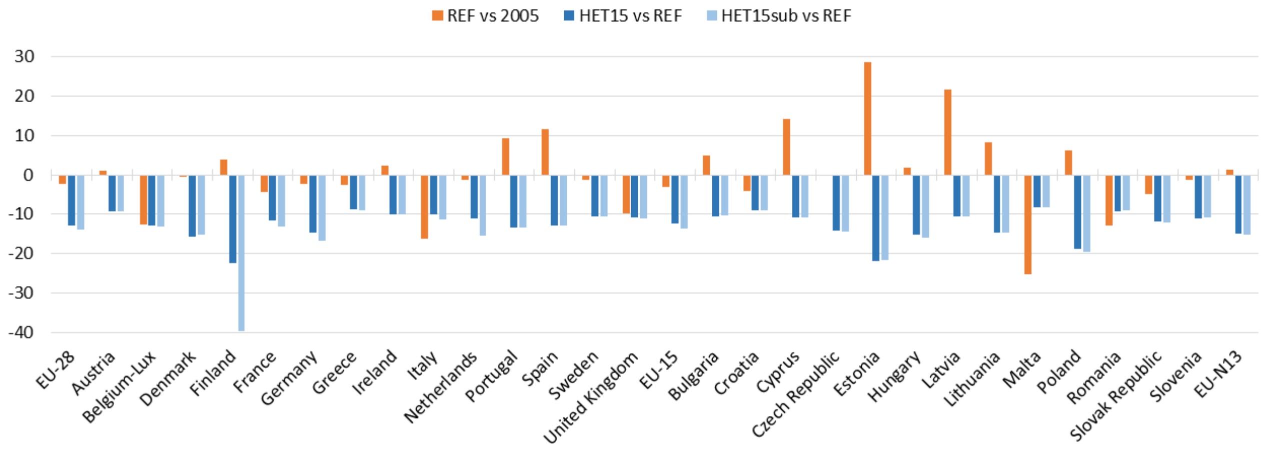
The emission reductions in the policy scenarios directly reflect the mitigation targets imposed per Member State, and they are achieved by both the reduction of activity levels and the application of mitigation technologies. In the HET15 scenario the EU-28 reduction target of 15% emission reduction compared to 2005 levels is almost precisely achieved [(–12.8% in HET15) + (–2.3% REF)]. In contrast, with a reduction of 16.3% compared with 2005, the envisaged aggregated EU-28 mitigation target is actually overachieved in the HET15sub scenario. This is because in several Member States the income-maximising mitigation, considering the subsidies paid for the application of mitigation technologies, exceeds the mitigation target, such that the target becomes irrelevant for some Member States. Finland, in particular, mitigates emissions far more than its

[4] For more information, see: http://ec.europa.eu/agriculture/cap-post-2013/index_en.htm

[5] The allocation of mitigation targets among Member States reflects the results of performing an auxiliary scenario that imposed a carbon price. For the mitigation policy scenarios we removed the carbon price but set binding mitigation targets at Member State level based on the distribution key of mitigation efforts achieved with the auxiliary scenario. Note that we removed the carbon price as it would put an additional cost burden to agriculture.

target, with mitigation at almost 40% in HET15sub compared with 22.5% in HET15. Noteworthy additional mitigation achievements in other Member States are projected for the Netherlands (4% more than in HET15), Germany (2% more) and Italy, Poland and Hungary (about 1% more each).

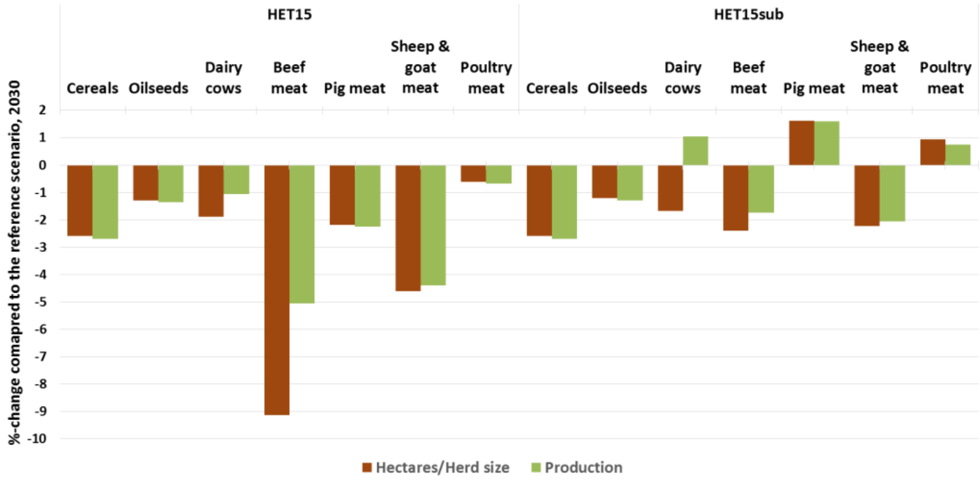
Figure 2: Percentage changes in agriculture GHG emissions per EU Member State (2030)



Impact on EU agricultural production and prices

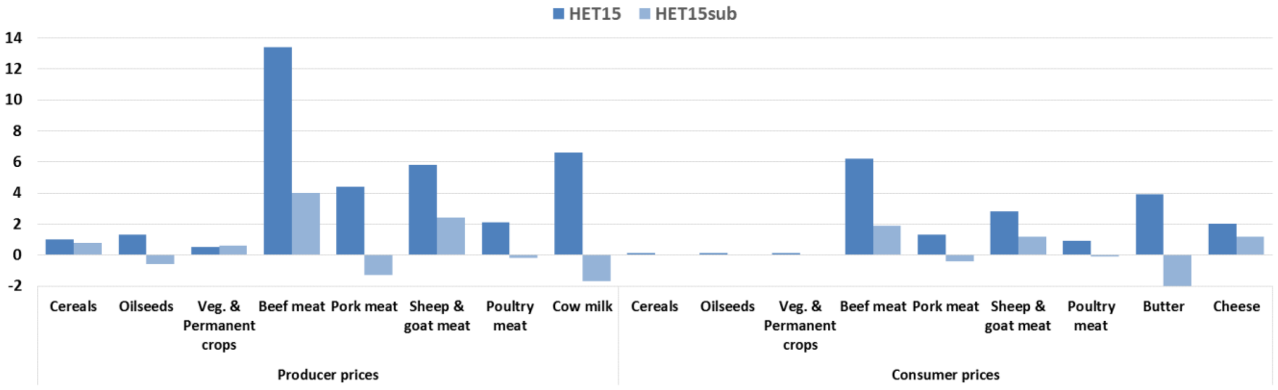
Figure 3 provides an overview of the effect of the modelled mitigation policies on agricultural activity levels in the EU. The largest effects in both scenarios are projected for the livestock sector, especially beef meat activities, followed by activities related to sheep and goats. However, when subsidies are paid for the uptake of mitigation technologies, the impact on activity levels in the livestock sector is significantly diminished, as, for example, the beef cattle herd size decreases by 9.1% in HET15 compared with 2.4% in HET15sub. In the crop sector, UAA decreases by 1.6% (–2.9 million ha) in HET15 and by 0.7% (1.3 million ha) in HET15sub, with cereal area decreases of 2.6% (1.5 million ha) and 1.3% (0.7 million ha), respectively. It can be noticed that in the HET15sub scenario an increase in EU-28 milk production is projected, even though dairy herd size decreases. This is directly attributable to the subsidised participation in the breeding programmes for higher milk yields, which is particularly pronounced in Ireland (+6.6% increase in milk production), Bulgaria (6.4%) and Romania (6.1%).

Figure 3: Percentage change in EU area, herd size and production compared to REF (2030)



The reduction in agricultural activity levels in HET15 lead to increases in prices. Accordingly, price increases are highest for beef production, followed by increases in milk prices. As impacts on production levels are generally lower in the HET15sub than in the HET15 scenario, prices also increase far less. However, for some commodities, agricultural production increases when subsidies are paid for the application of mitigation technologies, which can lead to a decrease in prices in the HET15sub scenario. This is particularly pronounced in the milk prices, but also occurs with regard to pork and poultry meat. Consumer price changes are in the same magnitude as producer price changes when looking at absolute changes, but due to high consumer margins (assumed constant), the relative changes are much lower (see Figure 4).

Figure 4: Percentage change in EU producer and consumer prices compared to REF (2030)



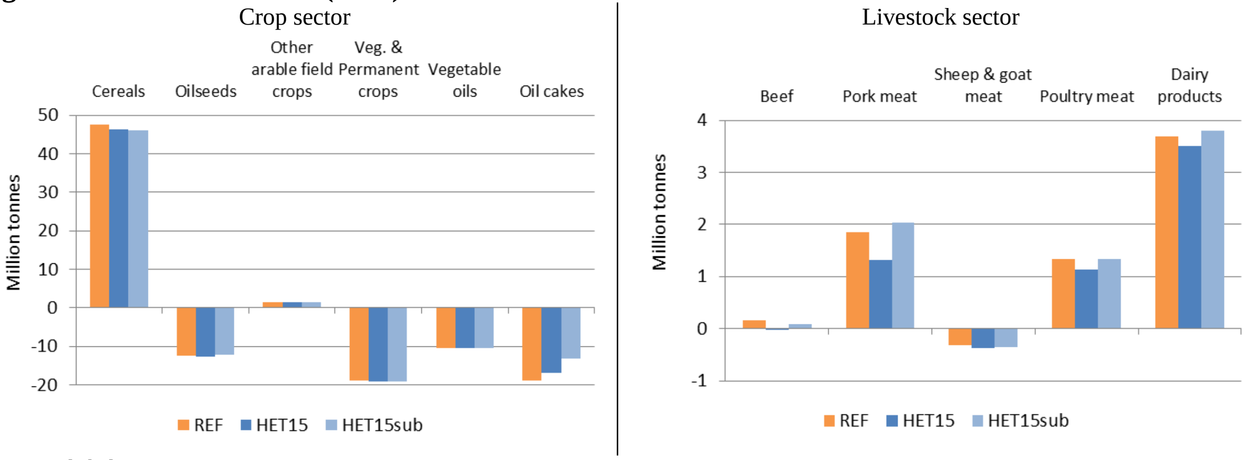
Note: The producer price is not applicable for dairy products (butter, cheese); the consumer price is not applicable for the milk aggregates.

Impact on the EU trade balance, consumption and emission leakage

The changes in EU production and prices lead to changes in the EU's agricultural trade balance (exports – imports) as shown in Figure 5. In the HET15 scenario, following the production and price developments, almost all agricultural EU exports decrease while at the same time imports increase, leading to a worsening of the EU trade balance of almost all agricultural products. The exception are oil cakes, where the trade balance improves due to lower feed demand from the livestock sector. In line with the production developments, relative changes in EU imports and exports are more pronounced in the livestock than in the crop sector (although the latter involves bigger quantities). Largest relative changes are indicated for meat products; however, for some of them, trade represents only a small proportion of domestic production. Beef meat shows an increase of 21% in imports and a drop of 40% in exports, and also the decreases in the EU net exports of pork meat (-29%), poultry meat (-15%), and dairy products (5%) are remarkable.

In the HET15sub scenario, the EU net trade position improves for several agricultural commodities even compared to the REF scenario. In line with the increased production levels in HET15sub, EU net exports increase especially for pork meat (+10%) and dairy products (+2.9%). Net exports in EU cereals (-3%) and oil cakes (-30%) are decreasing compared to the REF scenario, which in this case can be explained by increased EU domestic feed use owing to the production effects triggered in the HET15sub scenario.

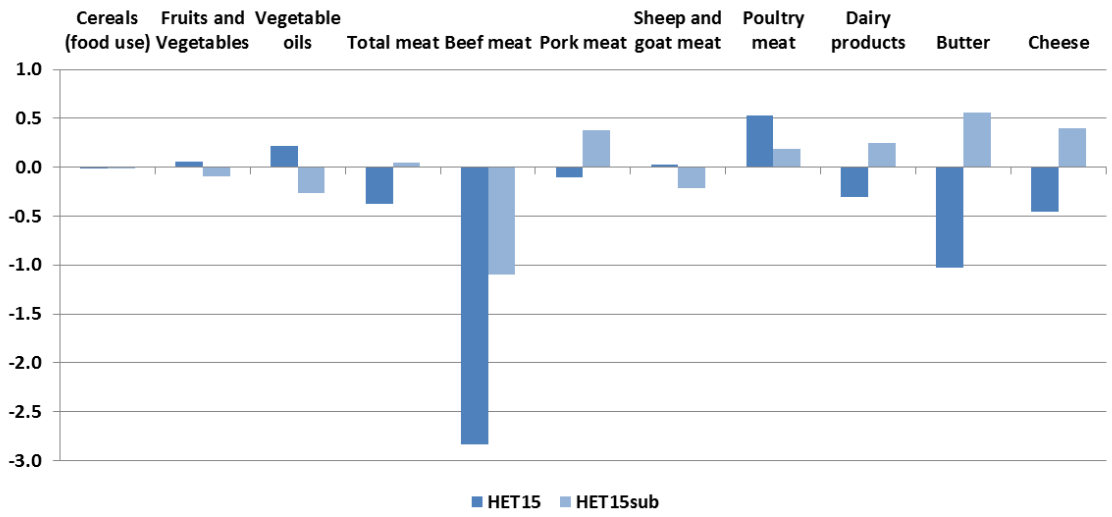
Figure 5: EU trade balance (2030)



Note: Trade balance = exports – imports.

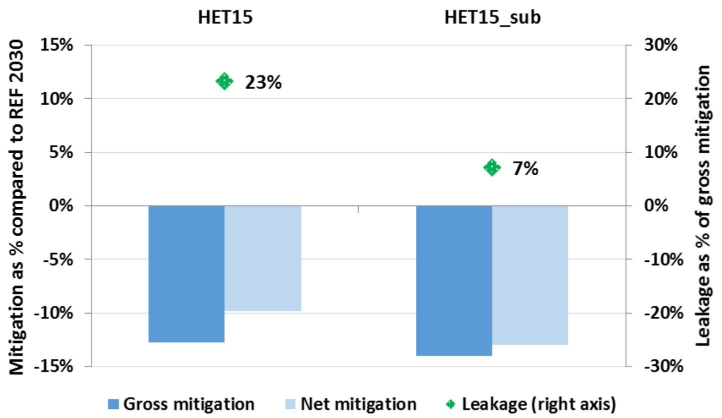
In both mitigation policy scenarios the increases in imports and the decreases in exports compensate to a large extend for the reductions in EU production. Therefore the final impact of the mitigation obligation on EU consumption appears to be of a relatively low magnitude for all agricultural commodities. In general, consumption decreases are less pronounced once the subsidies are paid for the application of mitigation technologies, which directly reflects the lower EU production decreases. In both scenarios, the biggest consumption decrease is projected for beef, however, total EU meat consumption decreases only by 0.4% in HET15, and even increases slightly by 0.1% in HET15sub. This is due to substitution effects, as in HET15 a shift from beef (-2.8%) and pork meat (-0.1%) to the cheaper poultry meat (+0.5%) occurs, whereas in HET15sub the decrease in beef (-1.1%) is more than compensated by consumption increases in pork (+0.4%) and poultry meat (0.2%) as the relative price for the latter two drops (even more for pork meat). Furthermore, in the HET15 scenario, the decreases in the consumption of meat and dairy products lead to slightly shifts towards vegetable oils (+0.2%), and fruit and vegetables (+0.1%). By contrast, in the HET15sub scenario the price decreases for pork and poultry meat as well as for dairy products lead to respective consumption increase (+0.2% in dairy products) and a consumption decreases of vegetable oils (-0.3%), and fruits and vegetables (-0.1%).

Figure 6: Percentage change in EU-28 consumption compared to REF (2030)



The changes in the EU trade balance go along with production increases outside the EU, which leads to an increase in agriculture emissions in non-EU countries, and hence emission leakage that can considerably diminish the global net effect of the EU´s emission reduction. Figure 7 shows that in the HET15 scenario about 23% of the mitigation effort in the EU is actually leaked due to production increases in non-EU countries. As EU production and the trade balance are less affected in the HET15sub scenario, emission leakage is reduced to 7%.

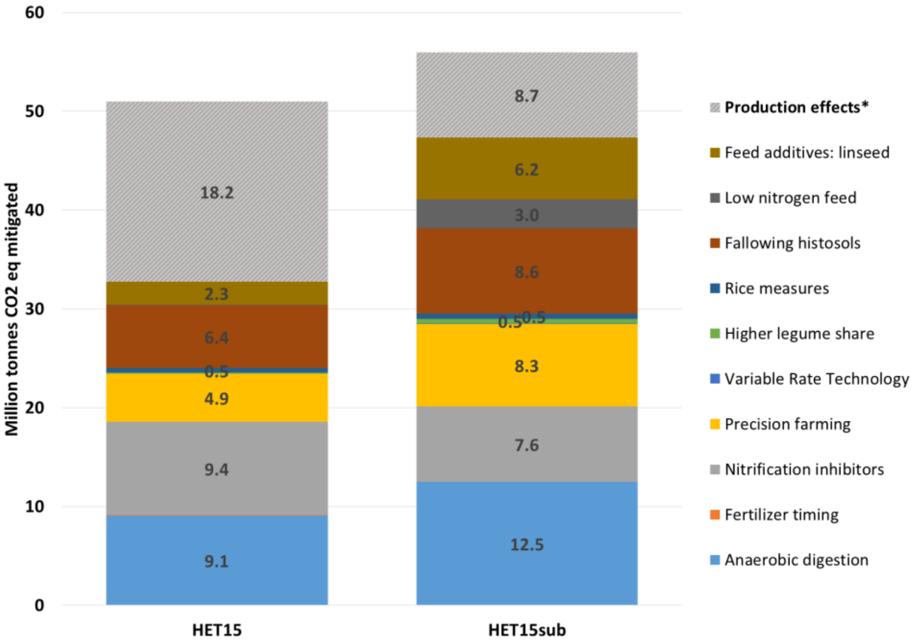
Figure 7: Mitigation and emission leakage compared to REF (2030)



Adoption of technological mitigation options

The analysis above shows that negative production effects are less pronounced in the HET15sub scenario compared to the HET15 scenario. This is directly linked to the subsidies paid for the application of mitigation technologies as they induce indeed an increase of the application, which in turn lessens the need to achieve emission reductions via changes in production levels. Therefore the level of emission reduction achieved via technologies rises from 64% (32.8 million tonnes of CO_2 equivalents) in the HET15 scenario to 85% (47.3 million tonnes of CO_2 equivalents) in the HET15sub, which, as mentioned above in the context of the emission results, actually means that the mitigation target is overachieved. Application generally increases for all technologies when subsidies are paid for their implementation, except for nitrification inhibitors, which are applied less, particularly because of the increase in precision farming (with the latter's contribution to emission reduction increasing from 4.9 to 8.3 million tonnes of CO_2 equivalents). Precision farming is more expensive than nitrification inhibitors, but it also has higher mitigation potential and generates higher income returns, which explains their increasing uptake once subsidies for technology application are paid. The subsidies also induce a considerable higher uptake of low nitrogen feed, a relatively expensive option in relation to its mitigation potential. The overall mitigation achievement and contribution by technology are depicted in Figure 8. It has to be noted that the presented level of mitigation achieved via mitigation technologies does not cover the mitigation achieved by the measures related to genetic improvements, as it is not possible to disentangle their mitigation effects from the related production effects. Nonetheless, a deeper look into the scenario results shows that methane emissions from enteric fermentation of dairy cows decrease in both scenarios, even though in the HET15sub scenario an increase in total milk production is projected. However, the decrease in enteric fermentation in dairy cows has to be seen in conjunction with all measures affecting methane emissions from enteric fermentation, e.g. together with linseed as a feed additive, the application of which is considerably higher in the HET15sub than in the HET15 scenario.

Figure 8: Overall mitigation achievement and contribution by technological mitigation option (2030)



* The mitigation effects linked to genetic improvement measures cannot be analysed in isolation and are included in the mitigation achieved by changes in production.

4 Conclusions

With this paper we want to further enhance the discussion on agriculture's possible contribution to emission mitigation in the EU. Therefore we specifically have a closer look on the potential of technological (i.e. technical and management-based) GHG mitigation options for EU agriculture, how their application might have to be activated, and how this could impact both agricultural market and emission developments. For the analysis we further developed the CAPRI model by including 12 specific endogenous technological non-CO_2 emission mitigation options and improving the respective modelling approach that considers also the influence of non-economic factors in terms of technology uptake.

In the reference scenario, agriculture emissions decrease by 2.3% in year 2030 compared to 2005, and scenario results show that the application of the considered mitigation technologies is very limited. This indicates that without further (policy) action the contribution of the agriculture sector to the EU mitigation efforts will be rather minor. The two mitigation policy scenarios with a 15% emission reduction obligation for EU agriculture show that setting a mitigation target substantially increases the uptake of mitigation technologies. Nonetheless, if no subsidies are paid for the application of the technologies, then the simulated mitigation target still leads to considerable production decreases in the EU, most pronounced in the livestock sector. The production decreases are not really matched by decreases in consumption, and therefore largely offset by production increases in other parts of the world. This causes emission increases in non-EU countries (emission leakage) that could considerably diminish the global net effect of EU mitigation efforts. In contrast, once technology uptake is subsidised, the share of mitigation technologies in total mitigation increases to 85%, which considerably decreases any adverse effects on EU agricultural production and emission leakage. In the scenario with subsidies it can also be seen that some of the modelled mitigation options might even result in EU production increases for some agricultural commodities. This is especially evident in the context of the increase in milk production, which is due to the uptake of the modelled breeding program for increased milk yields. However, while production increases, cow numbers decrease, which actually means more emissions per cow (a cow that produces more milk needs to eat more and hence also emits more), but less emissions per kg milk. The net effect in our scenario is still a net decrease in emissions related to milk production, but this has to be seen in conjunction with all modelled measures affecting methane emissions from enteric fermentation.

Our scenario results indicate that technological mitigation options could play an important role when it comes to agriculture's possible contribution to emission reduction in the EU. However, results also show that without incentives the application of mitigation technologies is very limited. An incentive to activate the uptake of mitigation technologies could be the setting of specific mitigation targets for agriculture, but even then negative production effects and emission leakage might outweigh the positive effects of technology application. A further incentive for technology uptake could be subsidising the application of mitigation technologies, and our results show that this could substantially increase the effectiveness of emission mitigation in EU agriculture. Such subsidies could come in many forms, like e.g. investment subsidies, but also though specific training and education programs.

It has to be stressed that the empirical evidence for the threshold values for the uptake of technological mitigation options in our modelling approach is very difficult to come by or non-existent. Further research is particularly needed regarding costs, benefits and uptake barriers of mitigation technologies (Soto et al., 2017). Despite the limitation with respect to the empirical basis, our modelling approach is in line with the existing literature on the general determinants of technology adoption in agriculture, and our scenario results unambiguously underline the importance of activating and supporting the uptake of mitigation technologies in order to effectively increase agriculture's contribution to emission mitigation in the EU.

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