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An economic assessment of GHG mitigation policy options for EU agriculture

EcAMPA 2

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Abstract
The project 'Economic Assessment of GHG mitigation policy options for EU agriculture (EcAMPA)' is designed to assess some aspects of a potential inclusion of the agricultural sector into the EU 2030 climate policy framework. In the context of possible reductions of non-CO_2 emissions from EU agriculture, the scenario results of the EcAMPA 2 study highlight issues related to production effects, the importance of technological mitigation options and the need to consider emission leakage for an effective reduction of global agricultural GHG emissions.

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Executive summary

The project 'Economic Assessment of GHG mitigation policy options for EU agriculture (EcAMPA)' is designed to assess some of the aspects of a potential inclusion of the agricultural sector into the EU 2030 policy framework for climate and energy. The results of the EcAMPA 1 study are published in a JRC Technical Report (Van Doorslaer et al. 2015). This EcAMPA 2 study further enhances the understanding on how non-CO_2 emissions from EU agriculture would evolve in a reference (business-as-usual) scenario, and to what extent technological (i.e. technical and management based) emission mitigation options could be applied by EU farmers and at which costs. For the analysis we employ the CAPRI modelling system. CAPRI is an economic large-scale comparative-static agricultural sector model with a focus on the EU (at regional, Member State and aggregated EU-28 level), but covering global trade of agricultural products as well. CAPRI is frequently used to simulate impacts of policy changes on agricultural production and demand from a regional to a global scale. The model endogenously calculates greenhouse gas (GHG) emissions for the major non-CO_2 sources in agriculture and, therefore, can analyse the effects of changes in policies and the market environment on GHG emissions.

GHG emissions in EU agriculture

The reporting of GHG emissions from agriculture in this study follows the common reporting format (CRF) of the United Nations Framework Convention on Climate Change (UNFCCC) as applied by the EU in spring 2015. The source category 'agriculture' only covers the emissions of nitrous oxide and methane. According to the CRF, emissions (and removals) of carbon dioxide (CO_2) from land use, land-use change and forestry (LULUCF) activities as well as 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 fertilisers) are attributed to other sectors and hence not considered in the report at hand. For the emission calculation and reporting, Global Warming Potentials (GWPs) of 21 for methane and 310 for nitrous oxide are used for conversion into CO_2 equivalents.

The historical development of aggregated EU-28 GHG emissions in the source category 'agriculture' shows a rather steady downward trend of –24%, from about 618 million tonnes CO_2 equivalents in 1990 to about 471 million tonnes CO_2 equivalents in 2012. However, the pace of reduction significantly slowed down in the last decade, with EU-28 agriculture GHG emissions decreasing by 16% in the period 1990 to 2000 and by 8% between 2001 and 2012. The general decrease in agricultural GHG emissions is mainly attributable to productivity increases and a decrease in cattle numbers, as well as improvements in farm management practices and the developments in and implementation of agricultural and environmental policies. According to the official inventories of the EU Member States, agriculture emissions accounted for 10.3% of total EU-28 GHG emissions in 2012. Depending on the relative size and importance of the agricultural sector, the contribution of agriculture emissions to the total national GHG emissions varies considerably between the EU Member States. The contribution is highest in Ireland (31%) and lowest in Malta (2.5%). France (19%), Germany (15%) and the United Kingdom (11%) together account for about 45% of total EU-28 agriculture emissions.

Scenario description

For this report, one reference scenario plus eight mitigation policy scenarios have been built. Assumptions regarding macroeconomic drivers, Common Agricultural Policy (CAP), market and trade policies are the same in all scenarios. Seven of the mitigation policy scenarios introduce a compulsory reduction of agriculture GHG emissions in the EU-28 in the year 2030, with the overall mitigation target being translated into differentiated emission reduction targets per Member State[1]. A certain number of technological GHG emission mitigation options is available in all scenarios. Assumptions regarding the mitigation technologies are mainly based on the GAINS database, but also on additional literature and expert knowledge. Depending on the specific scenario, either no subsidy or an 80% subsidy for the application of mitigation technologies is granted. In addition to the seven scenarios with compulsory mitigation targets, a scenario with an 80% subsidy for the voluntary application of mitigation technologies but without specific mitigation targets is simulated. Table A presents an overview of the scenarios and their narratives. The technological GHG mitigation options considered and their specific treatment in the scenarios are presented in Table B.

Table A: Scenario details

Scenario Name	Scenario description
Reference Scenario (REF)	– No specific mitigation target for EU-28 agriculture – No subsidy for the application of mitigation technologies – 'Restricted' potential of the mitigation technologies
Non-subsidised Voluntary Adoption of Technologies (HET20)	– Compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness – No subsidy for the application of mitigation technologies – 'Restricted' potential of the mitigation technologies
Subsidised Voluntary Adoption of Technologies (SUB80V_20)	– Compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness – 80% subsidy for the voluntary application of all mitigation technologies – 'Restricted' potential of the mitigation technologies
Subsidised Mandatory/Voluntary Adoption of Technologies (SUB80O_20)	– Compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness – 80% subsidy for the mandatory application of selected mitigation technologies and for the voluntary application of the remaining mitigation technologies – 'Restricted' potential of the mitigation technologies
Subsidised Voluntary Adoption of Technologies (with more rapid technological development) (SUB80V_20TD)	– Compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness – 80% subsidy for the voluntary application of all mitigation technologies – 'Unrestricted' potential of the mitigation technologies (i.e. more rapid technological development)
Complementary scenarios	
HET15, HET25	– Same as HET20, but with a compulsory 15% or 25% mitigation target for EU-28 agriculture, respectively, allocated to MS according to cost-effectiveness
SUB80V_15	– Same as SUB80V_20, but with a compulsory 15% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness
Subsidised Voluntary Adoption of Technologies, No Mitigation Target (SUB80V_noT)	– No specific mitigation target for EU-28 agriculture – 80% subsidy for the voluntary application of all mitigation technologies – 'Restricted' potential of the mitigation technologies

It has to be highlighted, that all mitigation policy scenarios are of an exploratory nature and that there is in fact no 'policy option' of this sort being considered in the current impact assessment work conducted by the European Commission. For example, there is no specific target for the agricultural sector considered in the EU Effort Sharing Decision (ESD). The 'expected contribution' from agriculture to the national ESD target is determined by each Member State and not implemented in the way of a hard target. It should also be noted that the scenarios refer only to the EU, not including for instance mitigation policies planned by non-EU countries for their respective agricultural sectors.

[1] This allocation is obtained based on a synthetic scenario that prices CO_2 equivalents of methane and nitrous oxide agricultural emissions equally across the EU-28.

Table B: Technological GHG emission mitigation options considered in the scenarios

Anaerobic digestion: farm scale[1]	Better timing of fertilization[2]	Nitrification inhibitors[2]
Precision farming[2]	Variable Rate Technology[1,2]	Rice measures
Fallowing histosols	Low nitrogen feed	Feed additives: linseed
Increasing legume share on temporary grassland[1]	Genetic improvements: increasing milk yields of dairy cows[2]	Genetic improvements: increasing ruminant feed efficiency
Feed additives: nitrate[3]	Vaccination against methanogenic bacteria in the rumen[3]	

[1] Mandatory to adopt in the scenario SUB80O_20 (but only for farmers fulfilling certain size criteria)
[2] Considered to have a higher potential in the scenario SUB80V_20TD (more rapid technological development)
[3] Only considered in scenario SUB80V_20TD (more rapid technological development)

Changes in GHG emissions from EU agriculture

The results reported here give a clear message regarding the potential contribution of the agriculture sector to the mitigation efforts of the EU. Basically, if no further (policy) action is taken, EU agricultural emissions are projected to decrease by 2.3% in year 2030 compared to 2005. This development of GHG emissions in the reference scenario is a result of the general policy, technology and market developments. By scenario design, the three mitigation policy scenarios without subsidies for the application of mitigation technologies (HET15/HET20/HET25) meet their respective mitigation target for EU-28 agriculture. Differences in mitigation between the three scenarios, at both aggregated as well as Member State level, are proportional, reflecting the applied linear increase in mitigation targets. The three scenarios with a 20% reduction target and subsidies for the application of mitigation technologies also meet the target by scenario design (some additional mitigation of about 0.5% can be observed, which is due to the interplay of endogenous variables in the model). By contrast, even though no specific reduction targets are assigned, the scenario SUB80V_noT shows an emission reduction of almost 14% compared to 2005. This is achieved by subsidising the mitigation technologies, which leads to a certain uptake of the technologies purely based on income gains for the farmer (i.e. the emission reduction is a positive side effect and not guaranteed like in the case of binding emission targets). Furthermore, in the scenario SUB80V_15, a reduction of 16.4% compared to 2005 is realised, i.e. the envisaged aggregated mitigation target of 15% is actually overachieved. This is because the income maximising mitigation, considering the subsidies paid for the application of mitigation technologies, exceeds the mitigation target in several Member States, such that the target becomes irrelevant.

Impacts on production

Agricultural production in the EU is most affected in the scenarios that do not contemplate subsidies for mitigation technologies. When subsides are paid for mitigation technologies, the impacts on production of a mitigation target are considerably reduced (Figure A), since the uptake of the mitigation technologies is preferred to the abandonment of production as a mitigation route.

At EU level, the largest production effects are in the EU livestock sector (and related fodder activities), with beef cattle production being the most affected, followed by activities related to sheep and goats. A compulsory mitigation target of -20 % without subsidies for mitigation technologies (HET20 scenario) would result in the EU-28 beef cattle herd decreasing by 16% and beef production by 9%. When subsidies are paid for mitigation technologies, the impact is reduced, with beef herd sizes decreasing by 10% and beef production by 6% (SUB80V_20 and SUB80O_20). Under the assumption of more rapid technological development (SUB80V_TD) decreases in herd sizes and production are further reduced.

The dairy sector is less affected than the beef meat sector, with reductions of the EU dairy herd size between 3.5% (HET20) and 2.5% (SUB80_20TD). While milk production in HET20 decreases by 2%, the subsidy paid for breeding programmes aiming at an increase in dairy cow yields leads to no change in total EU milk supply (SUB80V_20 and

SUB80O_20) or even to an increase of 1% when a more rapid technological development with a higher increase in milk yields is assumed (SUB80V_20TD).

The effects on EU crop production are rather moderate in relative terms in all scenarios, with agricultural area in the EU-28 decreasing between 3% (HET20) and 1% (SUB80V_20TD). However, in absolute terms this means a decrease in the Utilisable Agricultural Area (UAA) between 2.6 and 5.6 million ha. A substantial increase in set aside and fallow land in the EU-28 is observed in the scenarios with subsidies (between 39% or 2.6 million ha in SUBS80V_20TD and about 47% or 3.2 million ha in SUBS80O_20). Cereals production and cultivated area decrease in the EU-28 between 4% in HET20 and 2% in SUB80V_TD. Again, in the scenarios with subsidies paid for mitigation technologies, the reductions in production/area are smaller, and results indicate that it might in some countries even lead to an increase in cereal production compared to the REF scenario.

In the complementary scenarios, negative impacts on EU production are projected to be larger with no subsidisation and higher mitigation targets, whereas in the scenario without specific mitigation target and subsidies for the uptake of mitigation technologies (SUB80V_noT) the least negative impacts on production are observed. Due to the subsidised fallowing of histosols, set aside and fallow land would increase by 27% in the SUB80V_noT scenario, i.e. in a similar magnitude as in HET15. All meat activities are projected to increase in the SUB80V_noT scenario, regarding both herd size and supply at EU-28 level, e.g. in beef meat activities, EU-28 herd sizes increase by 2.4% and supply by 0.7%. For dairy cows, herd sizes are expected to decrease (-1%), whereas supply will increase by 1.5%, which is a direct consequence of the breeding programmes aiming at increasing milk yields. Cereal production is negatively affected, as hectares and production are slightly reduced (mainly due to the subsidised increase in fallowing histosols). The same effects as in SUB80V_noT can also be observed in the SUB80V_15 scenario, albeit at a lower level.

Figure A: Change in EU-28 agricultural production (%-change to REF, 2030)

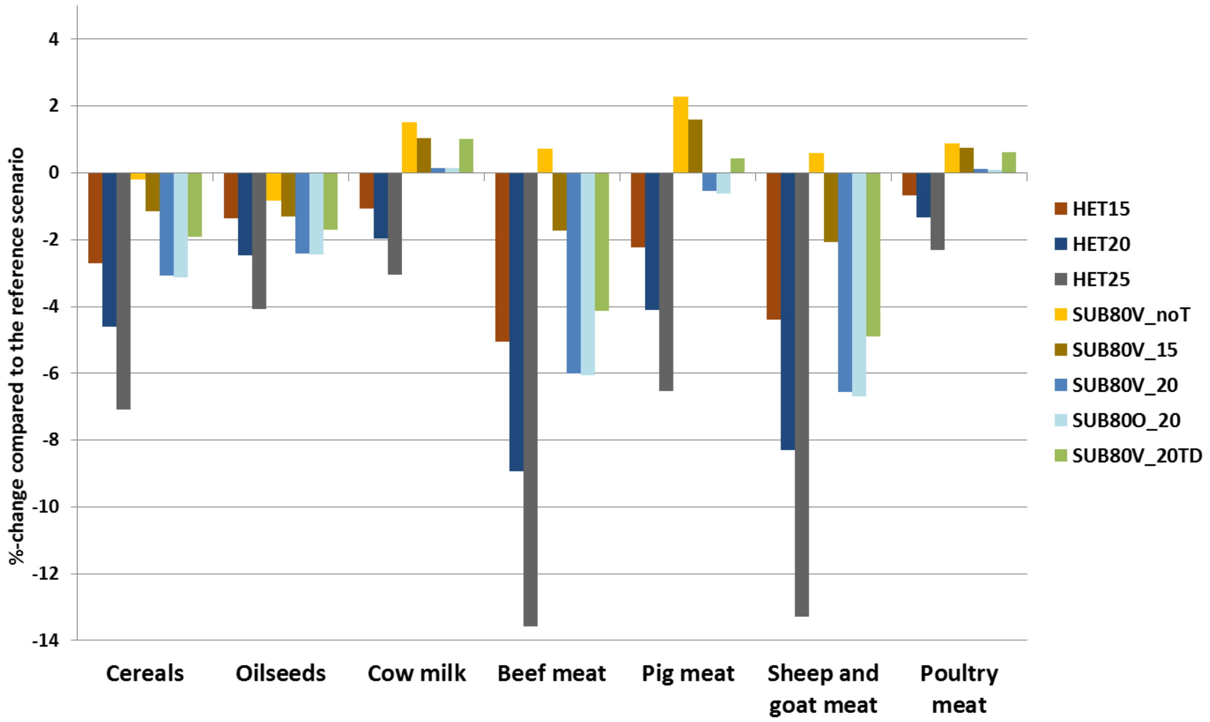


Figure A presents aggregated impacts on production at EU-28, yet the impact on agricultural production activities at Member State level is quite diverse between scenarios. This can be attributed to the following factors: (i) the specific mitigation target for each Member State, (ii) the relative profitability of the different agricultural production activities in each Member State, and (iii) whether subsidies are paid or not for the adoption of mitigation technologies. In all scenarios with mitigation targets the decrease in hectares or herd sizes is larger than the decrease in supply, which indicates some efficiency gains (i.e. higher yields). While part of these efficiency gains can be attributed to the use of technological mitigation options, a greater proportion might be attributed to changes in the production mix, such that activities with high emission intensities are reduced first, while more productive agricultural activities are maintained (for example, within a region less productive crops and animals might be taken out of production first).

Impacts on technology adoption

In the reference scenario, mitigation technologies are projected not to be widely implemented by farmers, since in many cases adoption is not profitable. When a mitigation target is made compulsory, farmers start adopting the technologies more widely, which helps complying with the mitigation targets. If no subsidies for technology adoption are paid (HET scenarios), the higher the compulsory mitigation target is fixed, the lower the share of emission reduction achieved via technologies. In other words, the higher the mitigation target is set, the higher is the share of mitigation achieved via changes in agricultural production. However, if subsidies are introduced for the mitigation technologies, the share of mitigation achieved via technologies instead of via production changes increases considerably (Table C). In the subsidy scenario with no mitigation target (SUB80V_noT), mitigation technologies are applied purely based on income maximising grounds (i.e. a specific technology will be applied on an agricultural activity if the marginal revenue of the activity plus the subsidies exceeds the costs of production) and not due to their effect on mitigating emissions.

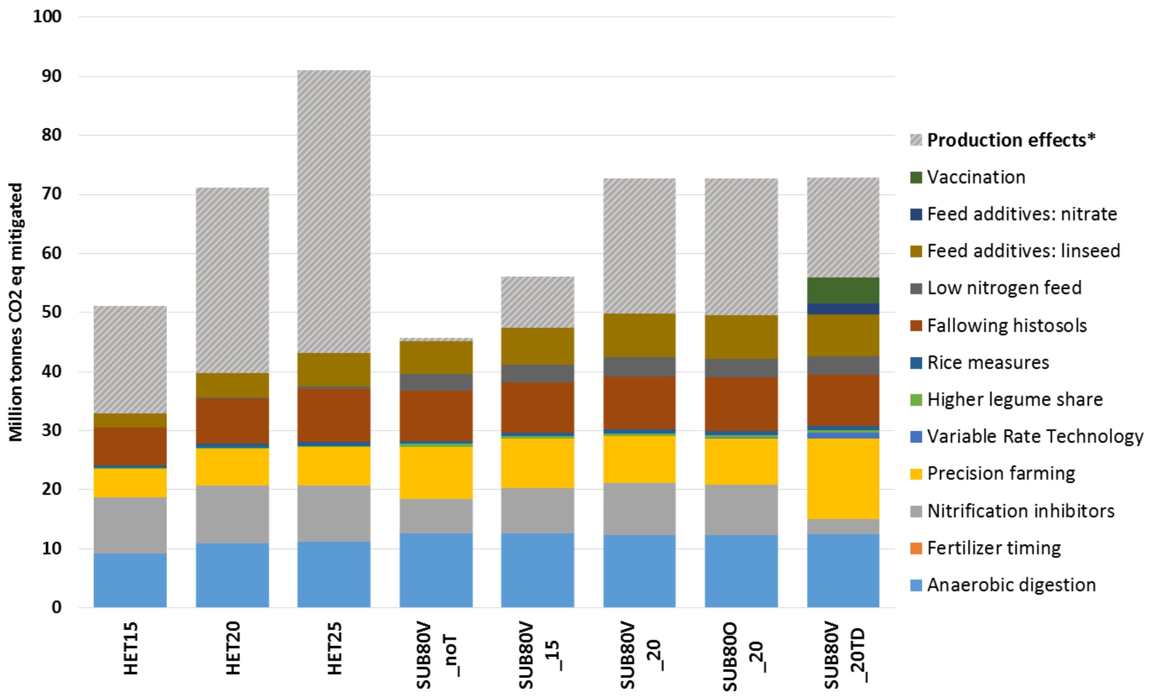
Table C: Share of EU-28 emission reduction achieved via the adoption of mitigation technologies and due to production changes

	HET15	HET20	HET25	SUB80V _noT	SUB80V _15	SUB80V	SUB80O	SUB80V _TD
	Share in total GHG emission reduction							
Mitigation technologies*	64%	56%	47%	99%	85%	68%	68%	77%
Production changes	36%	44%	53%	1%	15%	32%	32%	23%

* Does not include the mitigation effects from the measures related to genetic improvements as it is not possible to disentangle the effects of the breeding programmes on total agricultural emissions from their related production effects.

Among the technologies simulated in this study, anaerobic digestion (between 9.1 and 12.5 million tonnes CO_2 equivalents), nitrification inhibitors (between 2.5 and 9.8 million tonnes CO_2 equivalents), fallowing of histosols (between 6.4 and 9 million tonnes CO_2 equivalents), precision farming (between 4.9 and 16.6 million tonnes CO_2 equivalents) and linseed as feed additive (between 2.3 and 7.4 million tonnes CO_2 equivalents) have the largest contributions to total EU-28 emission reduction (Figure B). Scenario results also reveal that a general subsidisation of mitigation technologies does not necessarily lead to higher adoption of the most efficient technologies (i.e. in terms of mitigation potential). Depending on the mitigation technology, this is either because the maximum possible level of implementation set in the scenario or the cost-effective implementation level of the technologies defined in the model framework is reached. The SUB80V_noT (due to higher positive effects on farmers' income) and SUB80_TD scenarios (mainly due to the higher emission efficiency assumed in this scenario) furthermore show an increase in the contribution of precision farming at the expense of nitrification inhibitors.

Figure B: Contribution of each technology to total mitigation, EU-28 (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.

Impacts on prices and trade

Impacts on producer prices are directly related to whether emission mitigation targets are set and subsidy schemes are put in place in the different scenarios, as this in turn determines to what extent emissions are mitigated by the application of technologies or have to be achieved via changes in production. For instance, in the HET20 scenario producer prices are projected to increase much more than in the equivalent subsidy scenarios (SUB80V_20 and SUB80O_20), since there are no subsidies that facilitate switching the source of emission savings from production reduction to the adoption of mitigation technologies. Moreover, producer prices are more affected for those production activities that are more isolated from world markets (i.e. due to import tariffs or tariff rate quotas). Supply and demand elasticities in the EU and non-EU regions play an important role as well in determining price impacts. When non-EU supply is less responsive to price changes, there is less scope for cheaper imports to replace expensive domestic production and, therefore, average domestic prices increase.

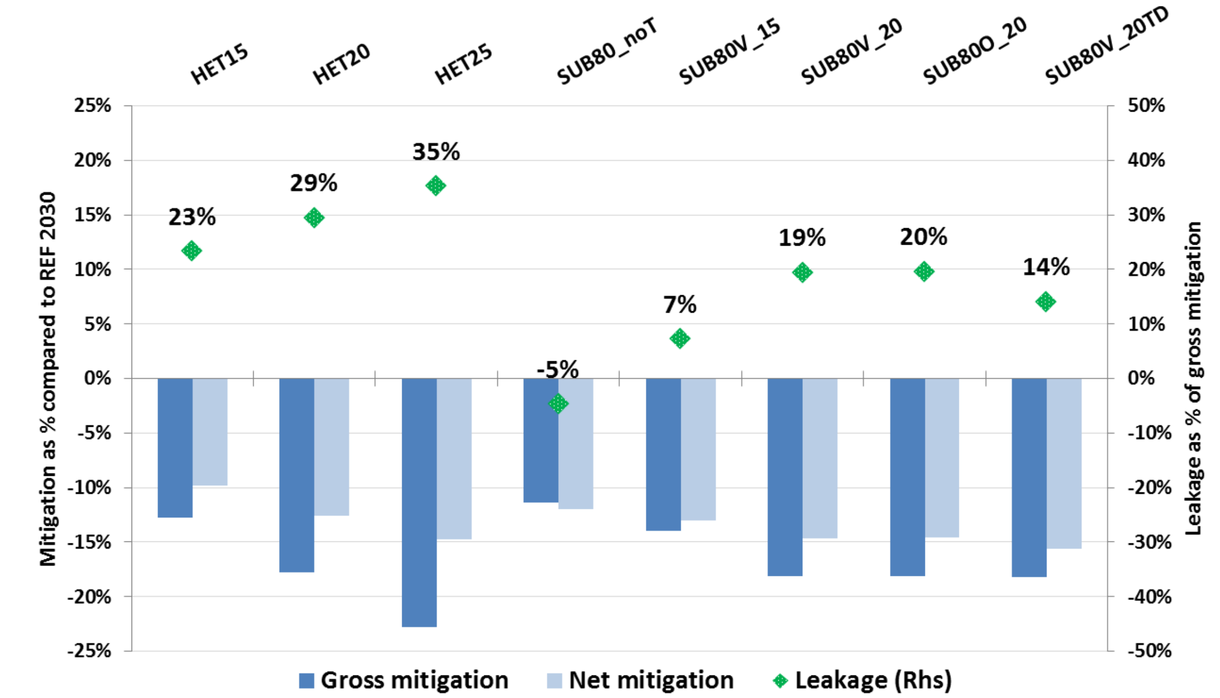
In the HET20 scenario, average EU producer prices increases are projected to range from 1% for vegetables and permanent crops to 26% for beef. In the subsidy scenarios, price increases are lower, especially regarding meat products (i.e. beef, pork, and poultry). In the scenario with subsidies and assumed more rapid technological development (SUB80V_20TD) and the scenario without emission target (SUB80V_noT), price changes become slightly negative for dairy products. This is related to the induced production increases, as especially the breeding for higher milk yields of dairy cows leads to efficiency gains in the dairy sector and results in an increase in total EU milk production.

Following the production and price developments, the net trade position of the EU is generally worsening, especially in the scenarios without subsidies for mitigation technologies. The largest relative changes in imports can be observed for meats, but with trade representing a very small share of domestic production. Again, the effects are generally reversed when a subsidy for the uptake of mitigation technologies is paid without specific mitigation targets in place (SUB80V_noT). The EU net trade position also improves for some agricultural commodities in the SUB80V_15 scenario. In line with increased production, EU exports increase especially for dairy products. Furthermore, the trade balance for dairy products is also improved in the SUBS80_20TD scenario, as the assumed more rapid development in breeding for milk yields leads to lower imports than in the REF scenario.

Impacts on global GHG emissions (emission leakage)

Due to the combined effects on production, prices and trade, the introduction of a unilateral emission reduction target in the EU generally leads to emission leakage, i.e. an increase in GHG emissions in other world regions through trade effects triggered by the assumed EU emission mitigation policy. Depending on the specific scenario, emission leakage can considerably downsize the net effect of EU mitigation efforts on global GHG emissions. Results show that an increase in the EU mitigation target generally goes along with an increase in emission leakage, with 23% (HET15), 29% (HET20) and 35% (HET25) of the mitigation achieved in the EU offset by emission increases in the rest of the world. Most of the additional emissions are expected in Asia and Central and South America. However, when the application of mitigation technologies is subsidised and GHG mitigation therefore achieved with lower impacts on production, the rate of leakage is reduced considerably: by about 10 percentage points in SUB80V_20 and SUB80O_20, and 15 percentage points in SUB80V_TD and SUB80V_15. This is because EU farmers mitigate more emissions via the use of technologies than by reducing production. Differently, subsidising mitigation technologies without a specific mitigation target (SUB80V_noT) could even lead to negative emission leakage, i.e. a decrease in emissions also outside the EU. This is due to the positive effect on EU production efficiency of some technologies (like e.g. the breeding programmes), leading to some production increases and the replacement of non-EU production with higher emission intensities by EU production exported (Figure C).

Figure C: Emission leakage per scenario (%-change to reference scenario, 2030)



Impacts on the EU budget and economic welfare

From a budgetary point of view, two main points can be derived from the policy scenarios. On the one hand, the setting of compulsory mitigation targets without financial support for technologies (HET scenarios) has no additional cost for the EU budget. However, as mentioned above, the impacts on domestic production can be significant and, furthermore, emission leakage is likely to considerably reduce the net effect of EU mitigation efforts on global GHG emissions (in the case that other parties would not implement agricultural emission reduction targets). On the other hand, the scenarios with subsidies for the adoption of mitigation technologies show significant budgetary costs, as farmers are projected to widely adopt the technologies.

Table D: Subsidies for mitigation technologies (EU-28), 2030

Scenario		Total subsidies to mitigation technologies (bio. Euro)	Subsidy per tonne total CO_2 mitigated (Euro/t)
Non-subsidised Voluntary Adoption of Technologies	HET15/HET20/ HET25	NA	NA
Subsidised Voluntary Adoption of Technologies, No Mitigation Target	SUB80V_noT	12.7	278
Subsidised Voluntary Adoption of Technologies	SUB80V_15	13.0	233
	SUB80V_20	13.6	188
Subsidised Mandatory/Voluntary Adoption of Technologies	SUB80O_20	13.7	188
Subsidised Voluntary Adoption of Technologies (with more rapid technological development)	SUB80V_20TD	15.6	215

Note: The subsidies presented in the table are for the projection year 2030, they are relative to the REF scenarios, and they are in prices of 2030.

From a sectoral perspective, economic welfare (i.e. only considering welfare linked to agricultural marketed outputs and not to e.g. environmental externalities) increases in all the scenarios without subsidies for the application of mitigation technologies. This positive net effect is a consequence of higher agricultural revenues and industry profits due to the higher producer prices, which are projected to over-compensate the losses by consumers. However, consumer surplus decreases considerably, as consumers are confronted with a decrease in purchasing power due to an increase in consumer prices. Economic welfare decreases in all other scenarios, ranging from -0.02% or -3.4 billion Euro (SUB80O_20) to -0.04% or -8.6 billion Euro (SUBV80_20TD) and even 11.8 billion Euro in the scenario SUB80V_noT. The negative economic welfare effect when subsidies are used is the consequence of a smoother increase in prices (which actually diminishes losses in consumer surplus, but also implies lower profits by the food industry) and large costs for taxpayers due to the introduction of mitigation subsidies. Agricultural income increases in the SUB80O_20 and SUB80V_20 scenarios by more than 10%, but less than 7% in the SUBV80_20TD, and only about 1% in the SUB80V_noT scenario. Regarding the projected increase in EU-28 agricultural income, several issues have to be highlighted: (i) farm income is not increasing proportionally to the subsidies paid for mitigation technologies, which is mainly due to lower increases (or even decreases) in agricultural prices compared to the scenarios without subsidies; (ii) income effects seem to vary considerably between Member States and agricultural commodities; (iii) the methodology used cannot provide results on the number of farmers/farms remaining active and benefitting from the potential increases in total agricultural income (i.e. farm-level structural change is not considered). Moreover, as only economic welfare effects for the agricultural sector can be considered, possible additional effects on other sectors, for example induced by decreases in consumer surplus or increases in taxpayer costs, are not covered in this modelling approach.

Conclusions and further research

In the context of possible reductions of non-CO_2 emissions from EU agriculture, the scenario results of the EcAMPA 2 study highlight issues related to production effects, the importance of technological mitigation options and the need to consider emission leakage for an effective reduction of global agricultural GHG emissions. More specifically, scenario results reveal the following four major points: (1) Without further (policy) action, agricultural GHG emissions in the EU-28 are projected to decrease by 2.3% by 2030 compared to 2005. (2) In our simulation scenarios, the setting of GHG emission reduction obligations for the EU agriculture sector without financial support shows important production effects, especially in the EU livestock sector. (3) The decreases in domestic production are partially offset by production increases in other parts of the world, what could considerably diminish the net effect of EU mitigation efforts on global GHG emissions. (4) Adverse effects on EU agricultural production and emission leakage are significantly reduced if subsidies are paid for the application of technological emission mitigation options. However, this comes along with considerable budgetary costs, as farmers are projected to widely adopt the technologies.

The results of this study have to be considered as indicative and contemplated within the specific framework of assumptions of the study. Follow-up work is planned to focus on the improvement of the modelling framework. The current methodology needs further refinements, especially regarding the representation of mitigation technologies and possible related subsidies. Therefore further research is particularly needed with respect to costs, benefits and uptake barriers of technological mitigation measures. Furthermore, agricultural carbon dioxide emissions have to be incorporated into the analysis. Moreover, further improvements regarding the estimation of emission leakage effects are required. Likewise it is necessary to closely observe how the global climate agreement reached at the COP21 in Paris will be put into action. Therefore, future studies have to consider how other parties integrate the agricultural sector into their Intended Nationally Determined Contributions under the Paris Agreement. In addition, for follow-up studies the emission factors used for calculation and reporting should be aligned to the Global Warming Potentials used in the latest Assessment Reports of the IPCC.

1 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 target for reduction of greenhouse gas (GHG) emissions, which the European Council agreed to be a reduction of at least 40 % by 2030 compared with 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 % emission reduction target, the sectors covered by the EU ETS will need to reduce their emissions by 43 % compared with 2005, and emissions from sectors outside the EU ETS (i.e. those covered by the ESD) will need to cut emissions by 30 % compared with the 2005 level. Furthermore, the agreement of the European Council states that the mitigation effort in the non-ETS sectors would have to be shared ‘equitably’ between the Member States (Council of the European Union, 2014; European Commission, 2014a).

So far, no decision has been made either on the concrete design of the new EU climate policy framework or on the specific involvement of the EU’s agricultural sector in mitigation obligations. However, the communication on the 2030 policy framework for climate and energy confirms that all sectors, including agriculture, should contribute to climate stabilisation and emission reduction in the most cost-effective way. Thus, a decision on the degree to which agriculture should contribute depends on the overall mitigation necessity, the mitigation potential of agriculture, and the costs of mitigation for and possible impacts on the agricultural sector.

Prior to this decision, to assess some of the manifold aspects of the potential inclusion of the agricultural sector, the European Commission’s Directorate-General for Agriculture and Rural Development (DG AGRI) asked the Joint Research Centre (JRC) to conduct the project ‘Economic Assessment of GHG mitigation policy options for EU agriculture (EcAMPA)’ between 2013 and 2014 (see Van Doorslaer et al., 2015).

Beginning in 2015, a follow-up study was commissioned to the JRC.[2] The main purpose of EcAMPA 2 is to identify the potential for cost-effective agricultural emission mitigation in the EU-28, which could be realised both via measures in line with the current Common Agricultural Policy (CAP) and with additional policies that could be implemented in a future reform of the CAP for the period 2021–2030. More specifically, the objectives of this project are:

- to provide an overview of the evolution of agricultural GHG emissions;
- to understand how agricultural emissions could evolve in a 2030 reference scenario, compared with historical trends;
- to understand which technological options could be applied by EU Member States for the reduction of non-CO2 emissions from agricultural sources and how much this would cost; moreover, to identify which options could be financed through subsidies;
- to assess whether or not the existing CAP budget and existing policy instruments would be adequate to guarantee emission reductions in agriculture over the medium and long term.

To achieve the objectives of the EcAMPA 2 project, several tasks were carried out:

- updating the information on agricultural GHG emissions in the EU, providing an overview of these emissions and of historical developments on the basis of the

[2] The work on EcAMPA 2 is realised through a close cooperation between JRC-IPTS (leading institution), JRC-IES, EuroCARE GmbH and the Swedish University of Agricultural Sciences.

most recent data (i.e. the latest published inventories by the European Environment Agency);

- organising a workshop with experts and stakeholders to review, discuss and share information on technological GHG mitigation options;
- updating the Common Agricultural Policy Regionalised Impact (CAPRI) model with regard to emission accounting and endogenous technological GHG mitigation options;
- creating a reference scenario and several mitigation policy scenarios for economic impact analysis.

The report at hand presents the outcome of the EcAMPA 2 project. It must be highlighted that all mitigation policy scenarios are hypothetical and illustrative, and do not reflect mitigation policies that are already agreed or currently under formal discussion in the EU.

We first present an overview and the historical developments of agricultural GHG emissions in the EU (Chapter 2). We then briefly describe the methodological framework of the study, delineating the major aspects of the model used for the analysis, as well as the approach taken for emission accounting and emission leakage (Chapter 3). Chapter 4 is dedicated to technological GHG mitigation options, describing the mitigation technologies considered, giving some general remarks on the adoption of technologies by farmers and presenting the methodology for modelling the costs and uptake of mitigation technologies. Chapter 5 outlines the major assumptions of the reference and mitigation policy scenarios. Scenario results are presented in Chapter 6 and the conclusions are given in Chapter 7. In the annexes, we first give some further information on the costs and modelling of technological mitigation options (Annexes 1 and 2). Moreover, we present the results of several sensitivity analyses: the impact of different assumptions on relative subsidies for technology adoption (Annex 3), the impact of different carbon prices on the distribution of mitigation efforts (Annex 4) and the impact of technological improvement in non-EU regions on emission leakage (Annex 5).

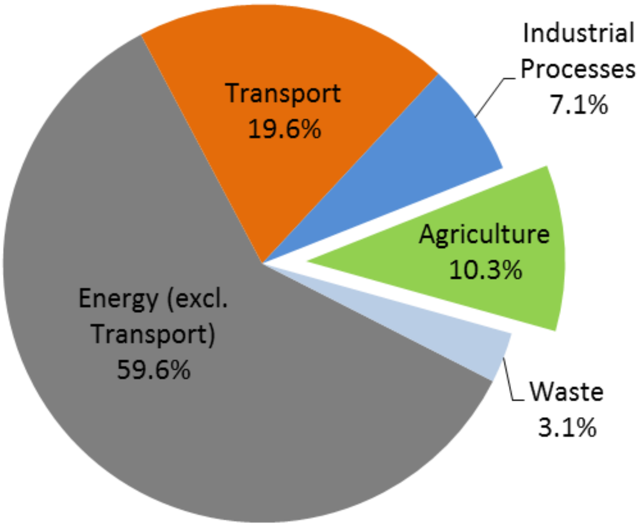
2 Agriculture GHG emissions in the EU: overview and historical developments

This chapter presents a brief overview of agricultural GHG emissions in the EU, including historical developments according to their most important sources. All figures presented are based on the official data compiled by the European Environment Agency (EEA) in the *EEA dataset v16*, published on March 2015.[3] For the emission reporting, Global Warming Potentials (GWPs) of 21 for methane and 310 for nitrous oxide are used for conversion into CO_2 equivalents.

2.1 Overview on agriculture GHG emissions in the EU

This overview section is based on reporting on emissions by the EU Member States and the latest available official data compiled by the EEA[4] and reported by the EU to the United Nations Framework Convention on Climate Change (UNFCCC). According to the common reporting format (CRF) of the UNFCCC, the inventory for the agriculture sector includes emissions of methane (CH_4) and nitrous oxide (N_2O). Emissions (and removals) of carbon dioxide (CO_2) from agricultural soils are not accounted for in the 'agriculture' category, but under the category 'land use, land use change and forestry' (LULUCF). Likewise, CO_2 emissions released by agricultural activities related to fossil fuel use in buildings, equipment and machinery for field operations are assigned to the 'energy' category. Other agriculture-related emissions, such as those from the manufacturing of animal feed and fertilisers, are included in the category 'industrial processes' (IPCC, 2006).

Figure 1: Contribution of agriculture emissions to total GHG emissions (excluding LULUCF) in the EU-28, 2012



Source: EEA (2015).

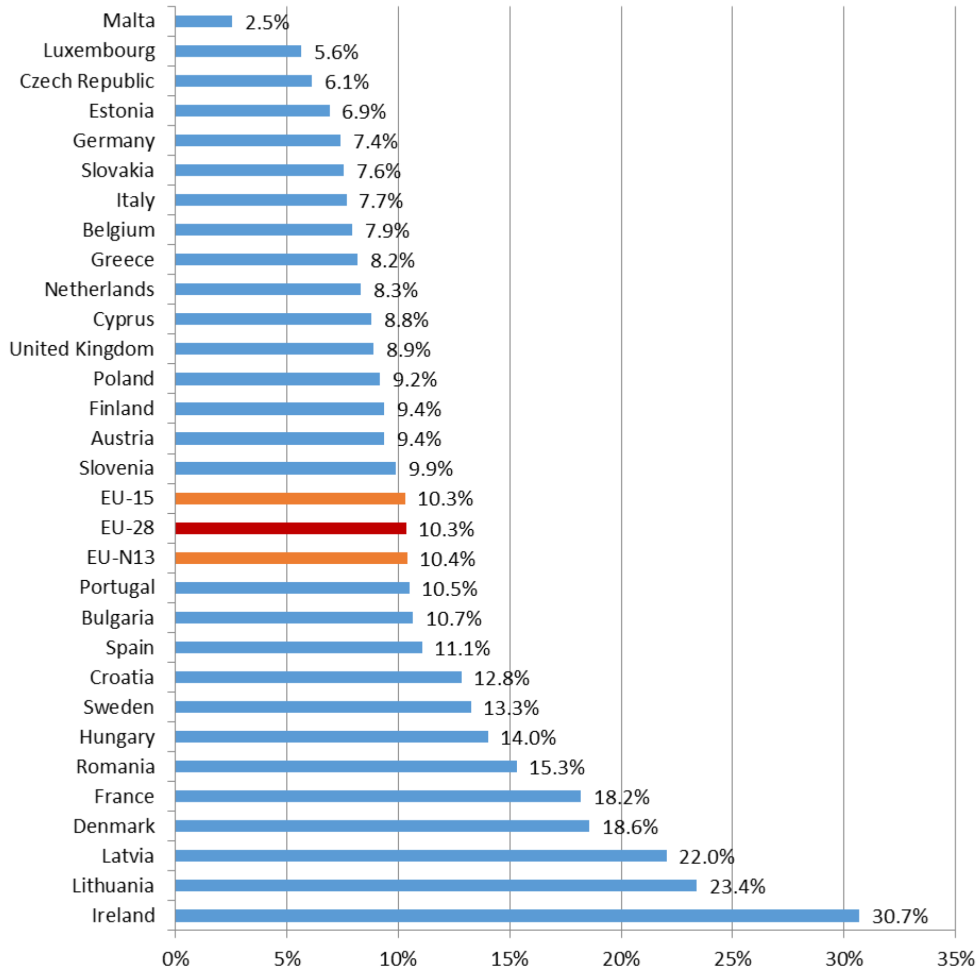
According to GHG inventories of the EU-28 Member States, GHG emissions in the source category 'agriculture' accounted for a total of 471 million tonnes of CO_2 equivalents in 2012. This represented 10.3 % of total EU-28 GHG emissions in 2012 (see Figure 1).

[3] For EcAMPA 1, we used the *EEA dataset v14*, published on 4 July 2013. Major parts of the text in this section are taken from the corresponding section in the EcAMPA 1 report, but updated with the data of the *EEA dataset v16* and some additional information on emissions in the Member States.

[4] The data is compiled by the EEA on behalf of the European Commission, in close collaboration with the EU Member States, the EEA's European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM), the European Commission's Joint Research Centre (JRC), Eurostat and the Directorate-General for Climate Action (DG CLIMA).

Depending on the relative size and importance of the agricultural sector, the contribution of agriculture emissions to the total national GHG emissions varies considerably between the EU Member States. The contribution is highest in Ireland (31 %), Lithuania (23 %) and Latvia (22 %), and lowest in Malta (2.5 %), Luxembourg and the Czech Republic (about 6 % each) (see Figure 2).

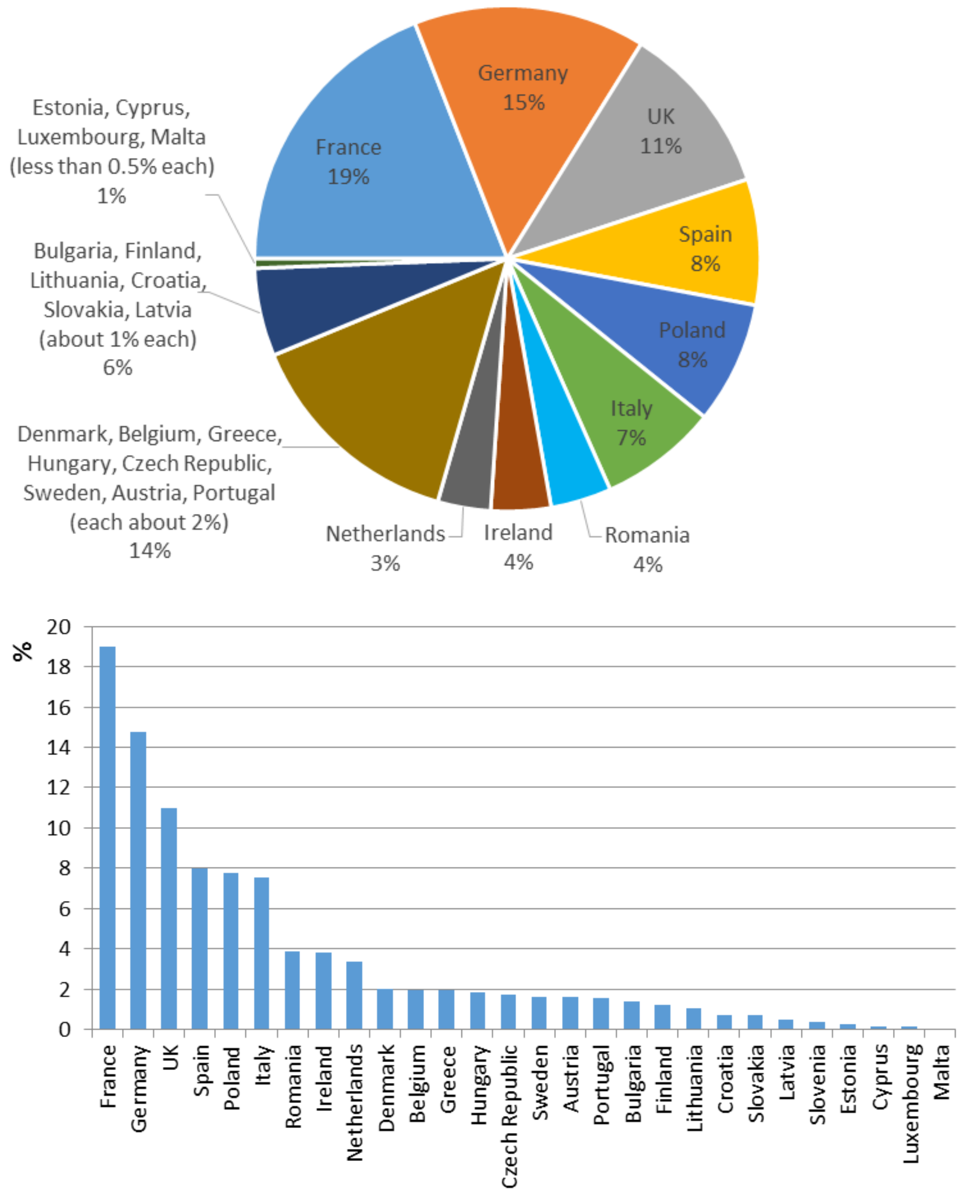
Figure 2: Contribution of agriculture emissions to total GHG emissions by EU Member State, 2012



Source: EEA (2015).

When looking at the total EU-28 agriculture GHG emissions, it is also important to highlight how they are distributed between Member States. As depicted Figure 3, in France (19 %), Germany (15 %) and the United Kingdom (11 %) together account for about 45 % of total EU-28 agriculture emissions, with the next highest contributions from Spain and Poland (8 % each), Italy (7 %), Romania and Ireland (4 % each) and the Netherlands (3 %). Eight Member States (Denmark, Belgium, Greece, Hungary, the Czech Republic, Sweden, Austria and Portugal) each have agriculture emissions of around 2 % of the EU-28 total, six Member States (Bulgaria, Finland, Lithuania, Croatia, Slovakia and Latvia) account for about 1 % each, and four Member States each account for less than 0.5 % of total EU-28 agriculture emissions, namely Estonia (0.3 %), Cyprus (0.2 %), Luxembourg (0.1 %) and Malta (only 0.02 %).

Figure 3: Contribution of Member States' agriculture emissions to total EU-28 agricultural GHG emissions, 2012



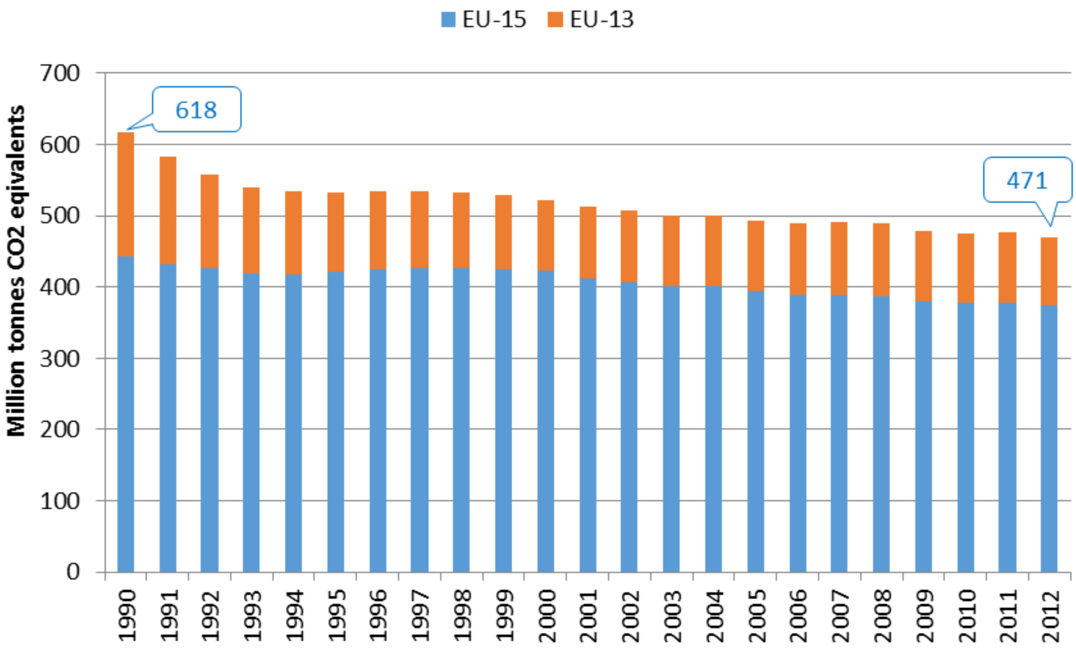
Source: EEA (2015).

2.2 Historical developments of agriculture GHG emissions in the EU

The historical developments of aggregated EU-28 agriculture GHG emissions show a rather steady downward trend of −24 %, from about 618 million tonnes of CO_2 equivalents in 1990 to about 471 million tonnes of CO_2 equivalents in 2012. While EU-15 emissions decreased by 15 % (−68.4 million tonnes of CO_2 equivalents), EU-N13 emissions decreased by 45 % (−78.8 million tonnes of CO_2 equivalents) over the period 1990 to 2012 (see Figure 4).

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 in and implementation of agricultural and environmental policies. Furthermore, these developments have been considerably influenced by adjustments to agricultural production in the EU-N13 following the changes in the political and economic framework after 1990 (see European Commission, 2009; EEA, 2013).

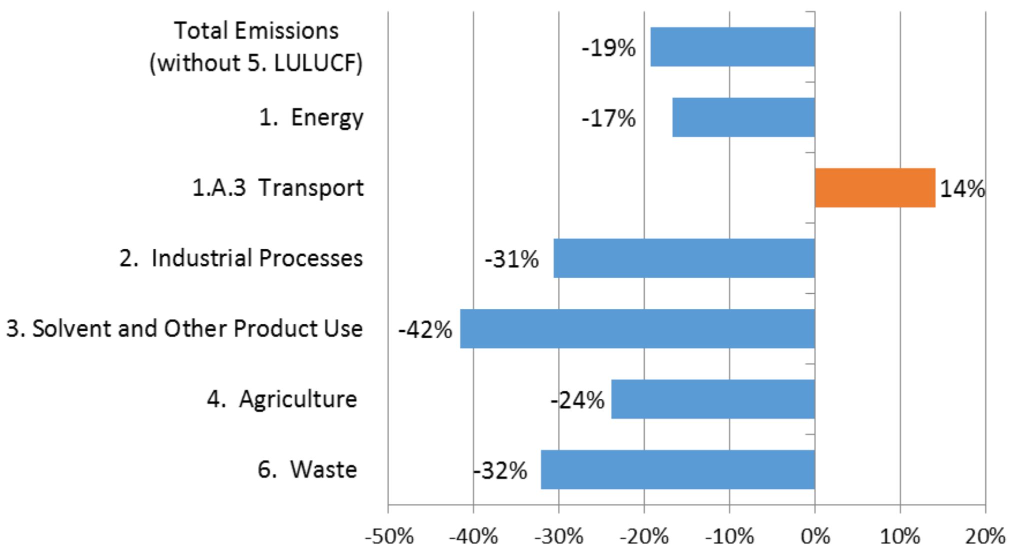
Figure 4: Development of agriculture GHG emissions in the EU, 1990–2012



Source: EEA (2015)

As can be seen in Figure 5, the relative reductions in EU-28 GHG emissions in the agriculture sector between 1990 and 2012 are less than the reductions achieved in the waste sector (−32 %) and industrial processes sector (−31 %) over the same time period, but higher than the trend in total EU GHG emissions, which decreased by 19 % (without LULUCF).

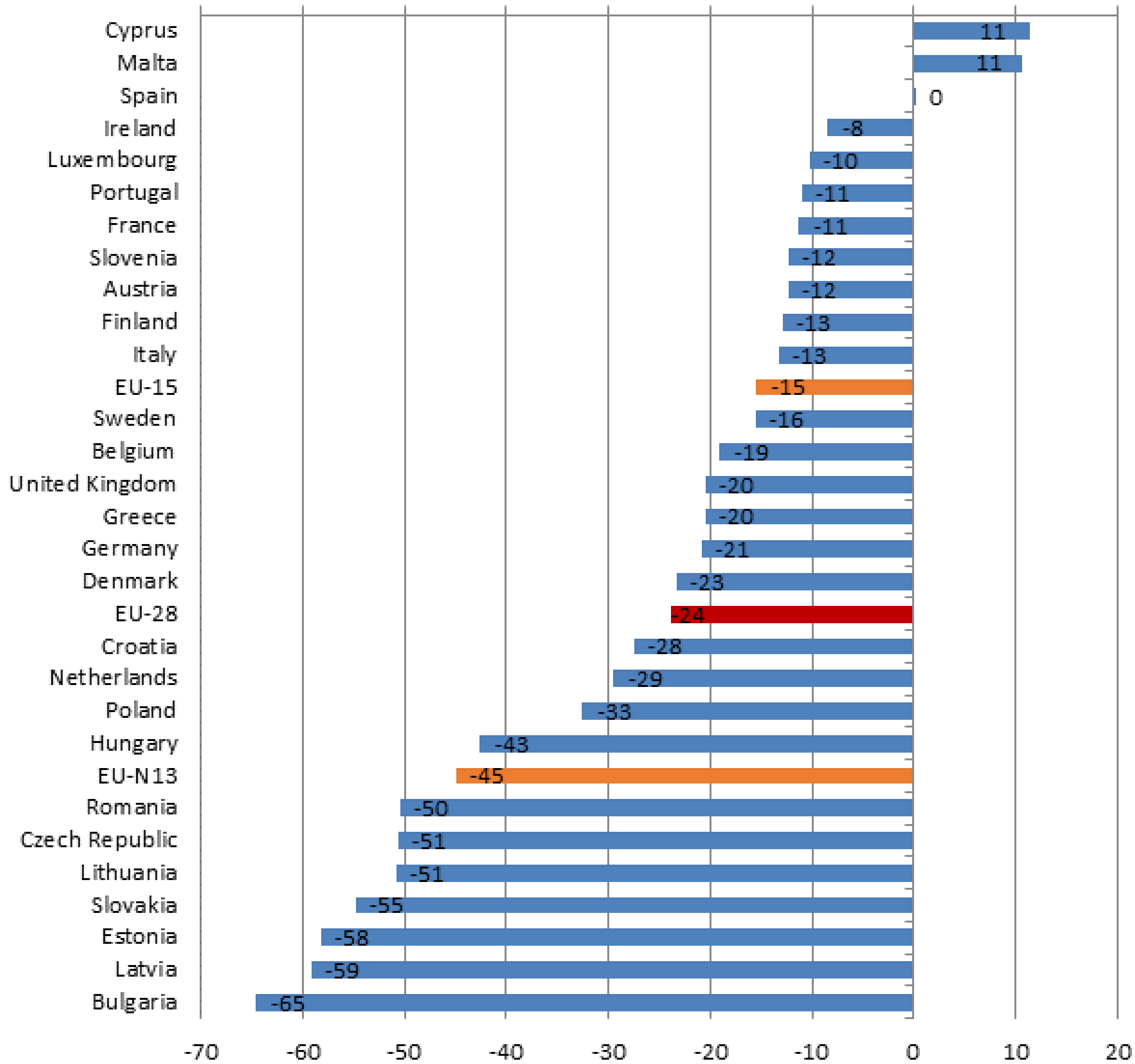
Figure 5: Changes in EU-28 GHG emissions by sector, 1990–2012



Source: EEA (2015)

In Figure 6, the average change in agricultural GHG emissions in terms of CO_2 equivalents between 1990 and 2012 is presented per Member State. On average, emissions have reduced by 24 % in the EU-28, with the largest relative reductions reported for nine EU-N13 Member States, headed by Bulgaria (−65 %), Latvia (−59 %) and Estonia (−58 %). In the same time period, the EU-15 Member States reduced their agricultural GHG emissions by 15 %, with the largest relative reductions reported for the Netherlands (−29 %), Denmark (−23 %) and Germany (−21 %). Overall, 25 of the Member States reported reductions in the absolute levels of agricultural GHG emissions between 1990 and 2012, and, while there was no change in the total level of agricultural GHG emissions reported in Spain, Malta and Cyprus are the only Member States where agricultural emissions actually increased during this time period (+11 % each).

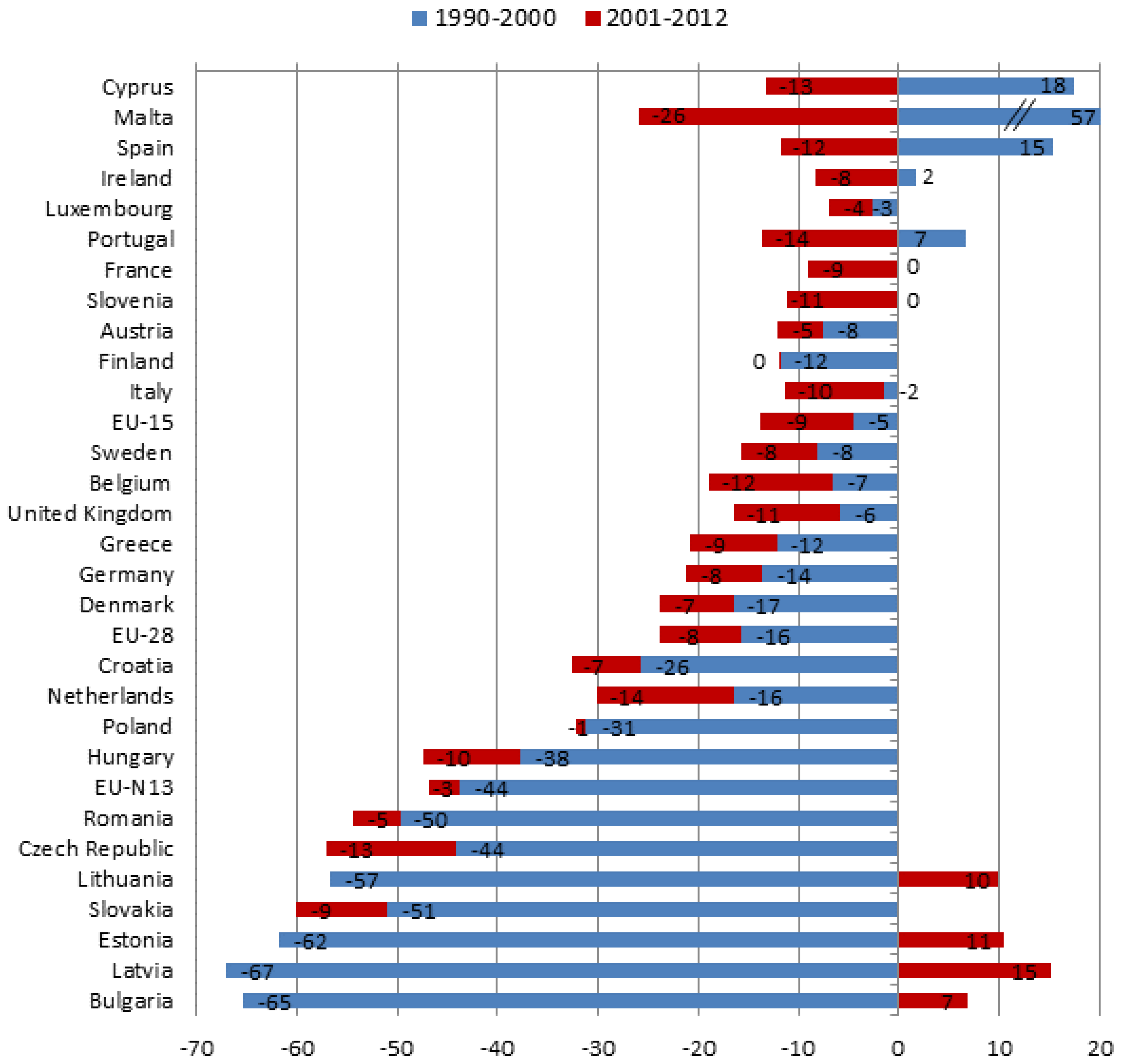
Figure 6: Changes in agriculture GHG emissions per Member State, 1990–2012 (%)



Source: EEA (2015)

Looking closer into the developments of agricultural GHG emissions per Member State, dividing the trend into two time periods shows that the majority of the decreases were achieved in the period between 1990 and 2000 and that, in most Member States, the pace of reduction significantly slowed down in the period between 2001 and 2012. This holds especially for the EU-N13 Member States, where, because of 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 the aggregated EU-28 level, agricultural GHG emissions decreased by 16 % in the period 1990 to 2000 and by 8 % between 2001 and 2012 (see Figure 7).

Figure 7: Changes in agriculture GHG emissions per Member State, between 1990–2000 and 2001–2012 (%)

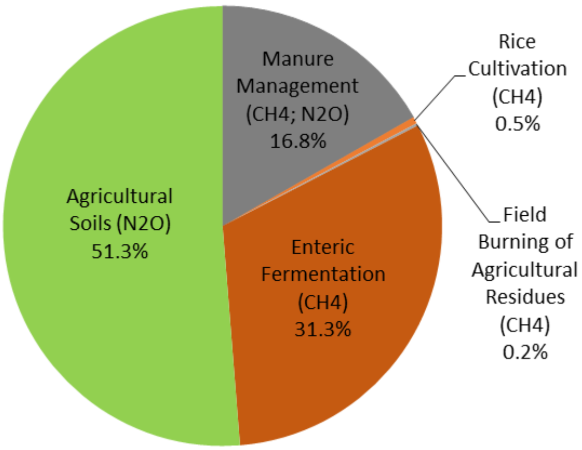


Source: EEA (2015).

2.3 Main sources of agriculture GHG emissions in the EU and their historical developments

The specific sources of GHG emissions in the agriculture sector of the EU-28 in 2012 can be divided into the following five source categories: enteric fermentation (31 %; CH_4), manure management (17 %; both CH_4 and N_2O), agricultural soils (51 %; N_2O), rice cultivation (0.5 %; CH_4) and field burning of agricultural residues (0.2 %; CH_4) (see Figure 8).

Figure 8: Breakdown of agriculture GHG emissions in the EU-28, 2012



Source: EEA (2015).

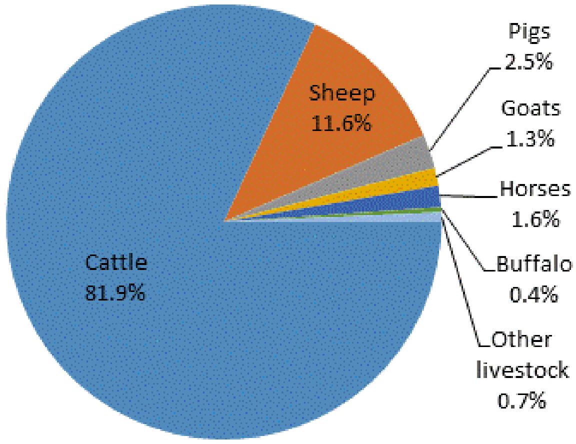
2.3.1 Enteric fermentation

Enteric fermentation occurs when CH_4 is produced during microbial fermentation in the digestive processes of livestock. The type of digestive system of the animal has a significant influence on the rate of CH_4 emissions; while ruminant livestock (e.g. cattle and sheep) are a major source of CH_4, non-ruminant livestock (e.g. horses and mules) and monogastric livestock (e.g. swine and poultry) produce only moderate amounts of CH_4. Apart from the digestive tract of the animal, the overall amount of CH_4 released depends on further animal and feed characteristics, such as the age and weight of the animal and the quality and quantity of the feed consumed (IPCC, 2006).

Enteric fermentation accounted for about 147 million tonnes of CO_2 equivalents (31 %) of the overall agricultural EU-28 emissions in 2012. Almost 94 % of the emissions in the source category 'enteric fermentation' stem from CH_4 emissions from cattle (about 82 %) and sheep (about 12 %) (see Figure 9). Accordingly, enteric fermentation in cattle is the largest single source of CH_4 emissions in the EU-28, accounting for almost 26 % of total agricultural emissions in the EU-28 in 2012. The proportion of the total EU-28 agriculture sector emissions coming from enteric fermentation in sheep was 3.6 %. Enteric fermentation in cattle in the EU-15 accounts for almost 70 % of the EU-28 emissions in this category, with the highest levels of emissions from enteric fermentation in cattle coming from France (17 %) and Germany (13 %), followed by the UK (8 %), Ireland, Italy and Poland (6 % each).

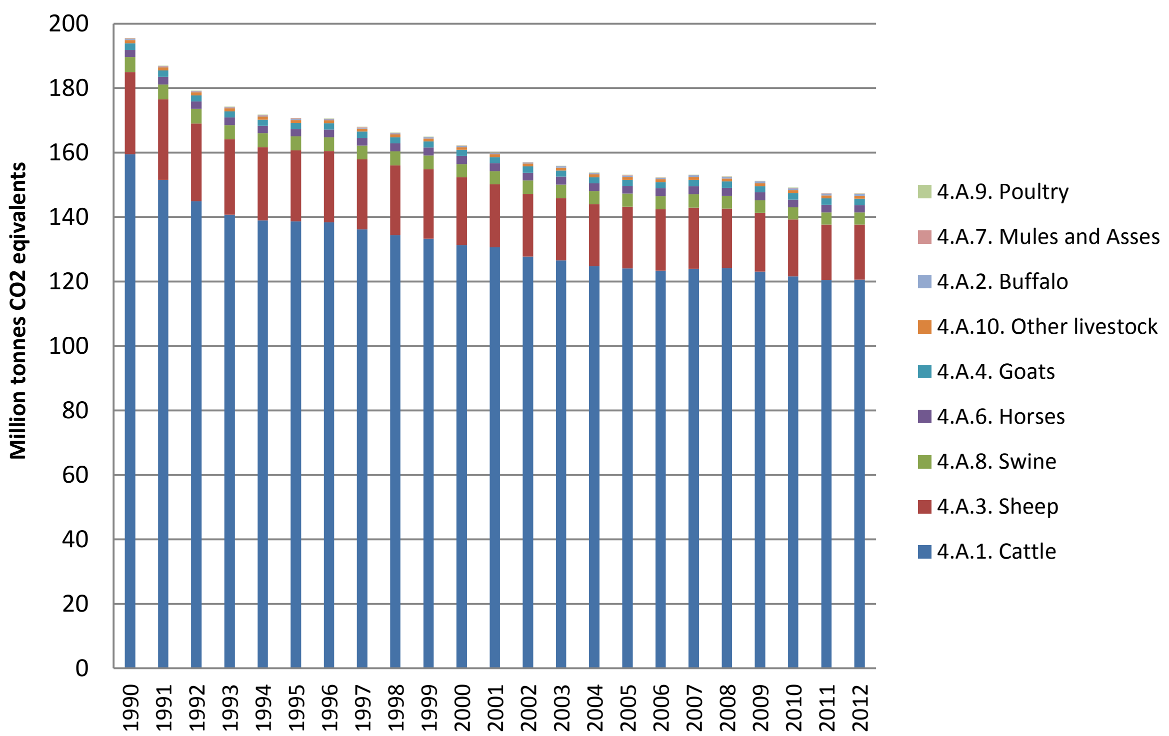
Between 1990 and 2012, EU-28 CH_4 emissions from enteric fermentation decreased by 24.6 % (about 48 million tonnes of CO_2 equivalents), with about 38.8 million tonnes of CO_2 equivalents of this coming from reductions in enteric fermentation in cattle and about 8.5 million tonnes from enteric fermentation in sheep (Figure 10).

Figure 9: Breakdown of emissions in the category enteric fermentation in the EU-28, 2012



Source: EEA (2015).

Figure 10: Development of EU-28 emissions in the category enteric fermentation, 1990–2012



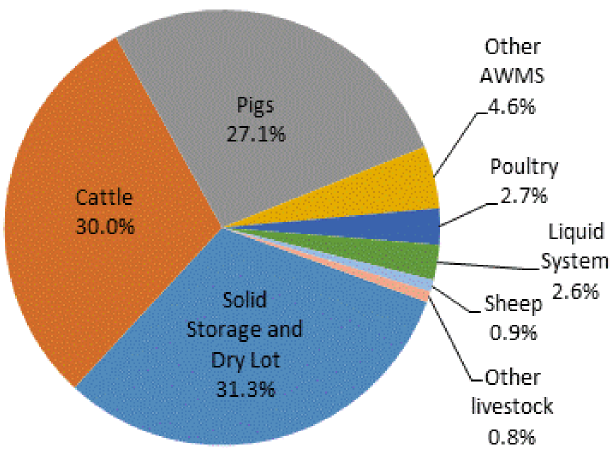
Source: EEA (2015).

2.3.2 Manure management

Livestock manure (i.e. dung and urine) is the second highest contributor to CH_4 agricultural emissions. However, during the storage and treatment of manure (i.e. before it is applied to the land or otherwise used), not only CH_4 released but also N_2O is released. CH_4 is produced from the decomposition of manure under anaerobic conditions, while N_2O is produced under aerobic or mixed aerobic and anaerobic conditions. The amount and type of emissions produced are related to the types of manure management systems used at the farm, and are driven by retention time, temperature and treatment conditions. Within the source category 'manure management', CH_4 emissions are categorised according to animal type and N_2O emissions are categorised according to the following waste management systems: anaerobic lagoon, solid storage and dry lot, liquid system, and other animal waste management systems. It should be noted that, according to IPCC guidelines, N_2O emissions generated by manure in the system 'pasture, range, and paddock' occur directly and indirectly from the soil and are, therefore, not attributed to manure management but to the source category 'agricultural soils'. Furthermore, CH_4 emissions associated with the burning of dung for fuel are not accounted for in the 'agriculture' category but are instead reported under the category 'energy' or 'waste' (the latter if it is burned without energy recovery) (IPCC, 2006). The breakdown of emissions in the category 'manure management' for the EU-28 in 2012 is presented in Figure 11.

Manure management accounts for approximately 78.9 million tonnes of CO_2 equivalents, i.e. 16.8 % of the total agriculture sector emissions in the EU-28. CH_4 emissions from manure management in cattle and swine production systems are important for many Member States, with emissions of 23.7 million tonnes of CO_2 equivalents in cattle production systems and 21.3 million tonnes of CO_2 equivalents in pig production systems in the EU-28 (representing 5 % and 4.5 % of the total EU-28 agriculture sector emissions, respectively). The highest emissions from cattle manure management in the EU-28 are in France (7.4 % of the EU-28 total), the United Kingdom (5.3 %) and Germany (4 %), whereas Spain (6.6 %) and France (4.7 %) have the highest emissions from pig manure management in the EU-28.

Figure 11: Breakdown of emissions in the category manure management in the EU-28, 2012

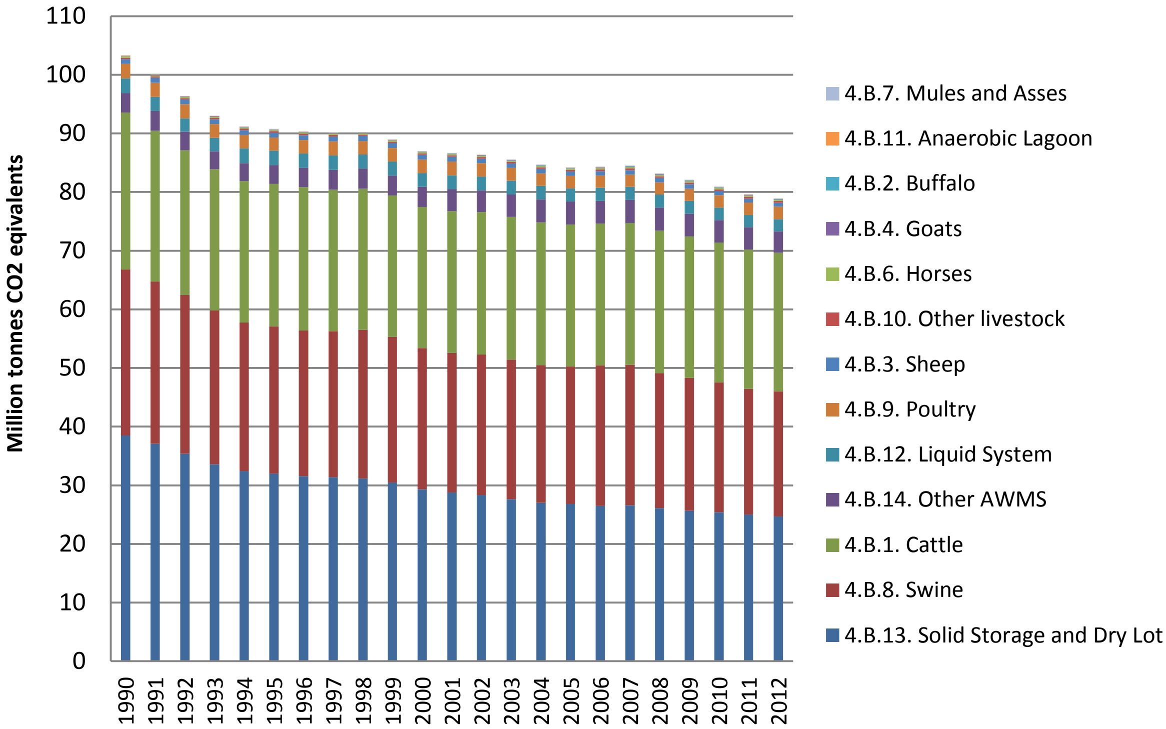


Note: AWMS = animal waste management system. Data categorised by animal type = CH_4 emissions; data categorised by management system = N_2O emissions.
Source: EEA (2015).

N_2O emissions from the manure storage system 'solid storage and dry lot' accounted for 24.7 million tonnes of CO_2 equivalents in the EU-28 in 2012 and, thus, for 5.2 % of total agriculture emissions. Poland (6.1 %), France (6 %) and Italy (3.9 %) are the Member States contributing the highest proportions of the EU-28 total emissions from the manure storage system 'solid storage and dry lot'.

EU-28 emissions in the source category 'manure management' decreased by 23.6 % (about 24.4 million tonnes of CO_2 equivalents) between 1990 and 2012 (Figure 12).

Figure 12: Development of EU-28 emissions in the category manure management, 1990–2012



Note: Data categorised by animal type = CH_4 emissions; data attributed categorised by management system = N_2O emissions.
Source: EEA (2015).

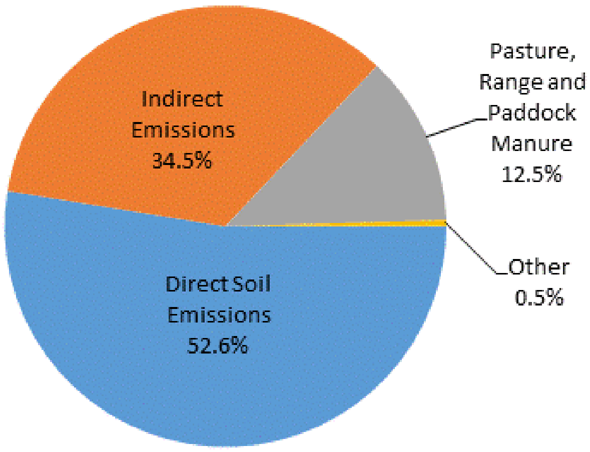
2.3.3 Agricultural soils

The natural processes of nitrification and denitrification produce N_2O in soils. A variety of agricultural activities increase mineral nitrogen availability in soils directly or indirectly and, thereby, increase the amount available for nitrification and denitrification, ultimately leading to increases in the amount of N_2O emitted. The N_2O emissions reported under the agricultural subcategory 'direct soil emissions' consist of the following anthropogenic input sources of nitrogen soil: application of mineral nitrogen fertiliser, application of managed livestock manure, biological nitrogen fixation, and nitrogen returned to the soil by the process of mineralisation of crop residues. The subcategory 'pasture, range and paddock manure' covers N_2O emissions from manure deposited by grazing animals. The subcategory 'indirect emissions' covers N_2O emissions that occur through the following two processes: (1) nitrogen volatilisation and subsequent atmospheric deposition of applied/mineralised nitrogen, and (2) nitrogen leaching and surface runoff of applied/mineralised nitrogen into groundwater and surface water (IPCC, 2006). Figure 13 presents the breakdown of emissions in the category 'agricultural soils' for the EU-28 in 2012.

In 2012, agricultural soil management accounted for emissions of about 241 million tonnes of CO_2 equivalents in the EU-28, representing 51.3 % of total agricultural emissions. Emissions in this source category consist largely of direct N_2O emissions from agricultural soils (52.6 % or 126.8 million tonnes of CO_2 equivalents). Direct soil emissions account for about 27 % of total EU-28 agriculture sector emissions and are the result of the application of mineral nitrogen fertilisers and organic nitrogen from animal manure. The Member States contributing the highest proportions of the total EU-28 direct soil emissions are Germany (10.7 %), France (8.7 %), Poland (5.2 %) and the United Kingdom (4.7 %). Indirect N_2O emissions from soils account for 34.5 % (83.2 million tonnes of CO_2 equivalents) of emissions in the category 'agricultural soils', representing 17.7 % of total EU-28 agriculture emissions. Indirect soil emissions are highest in France (6.9 % of EU-28 agricultural soil emissions), Germany (5.7 %) and the United Kingdom (3.9 %). N_2O emissions from 'pasture, range and paddock manure' account for 12.5 % (30.5 million tonnes of CO_2 equivalents) of emissions in the category 'agricultural soils' and represent 6.4 % of the total EU-28 agricultural emissions. France (3.4 %), the United Kingdom (2.4 %) and Ireland (1.1 %) are the only Member States where 'pasture, range and paddock manure' emissions account for greater than 1 % of the total EU-28 agricultural soils emissions.

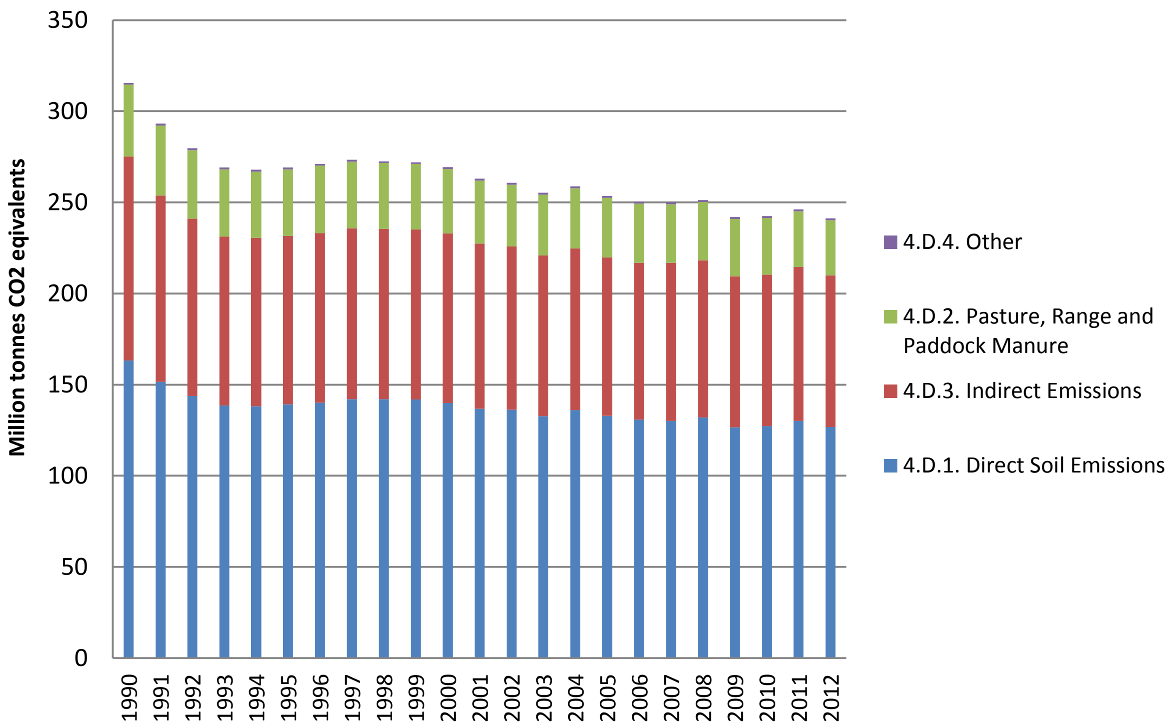
Between 1990 and 2011, EU-28 emissions in the source category 'agricultural soils' decreased by 22 % (about 69 million tonnes of CO_2 equivalents) (Figure 14.

Figure 13: Breakdown of emissions from the category agricultural soils in the EU-28, 2012



Source: EEA (2015).

Figure 14: Development of EU-28 emissions in the category agricultural soils, 1990–2012

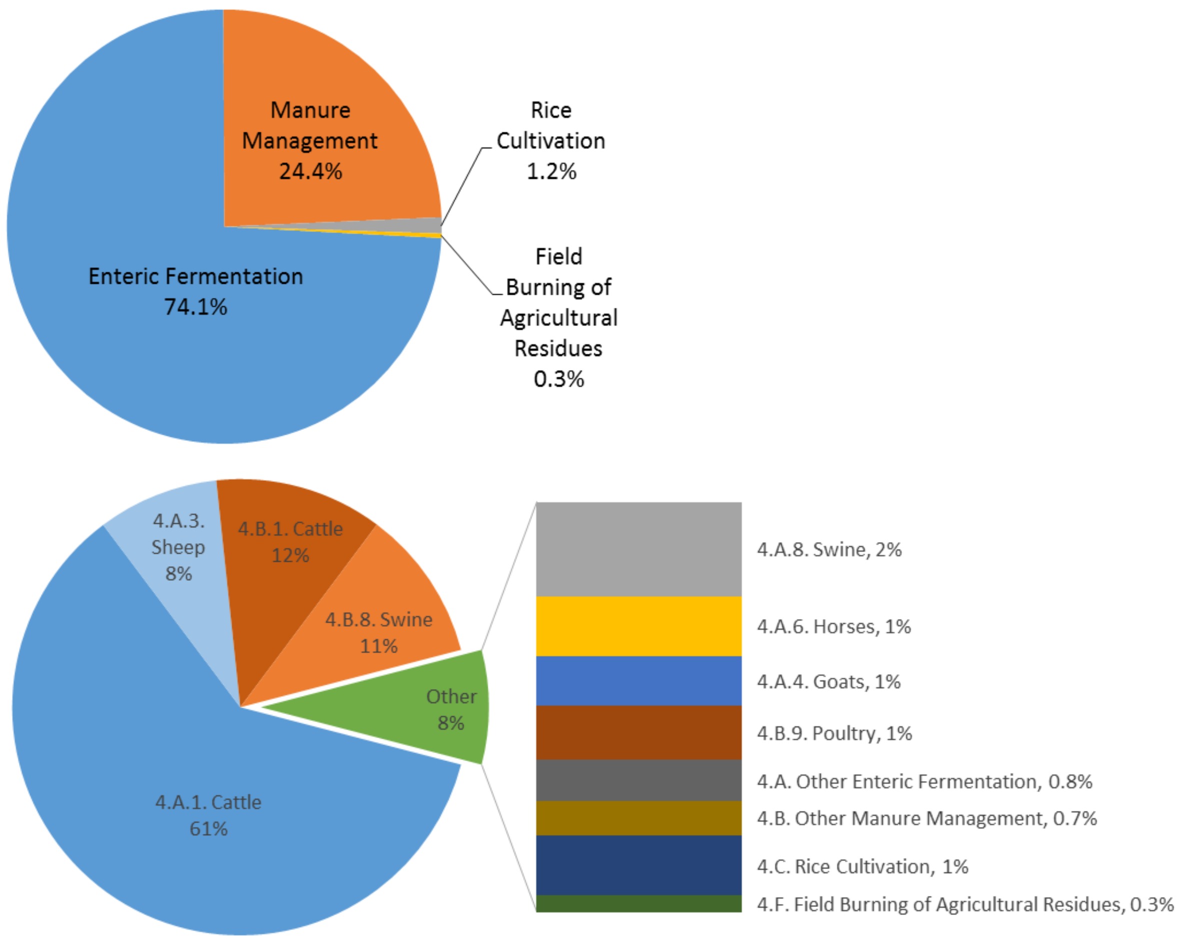


Source: EEA (2015).

2.4 Agricultural emissions of methane and nitrous oxide and their historical development

As highlighted above, the two main sources of CH_4 emissions from the agriculture sector are enteric fermentation in ruminants and manure management, accounting for 74.1 % and 24.4 % of EU-28 CH_4 emissions, respectively. Rice cultivation (1.2 %) and field burning of agricultural residues (0.3 %) make only a very small contribution to EU-28 CH_4 emissions (see Figure 15).

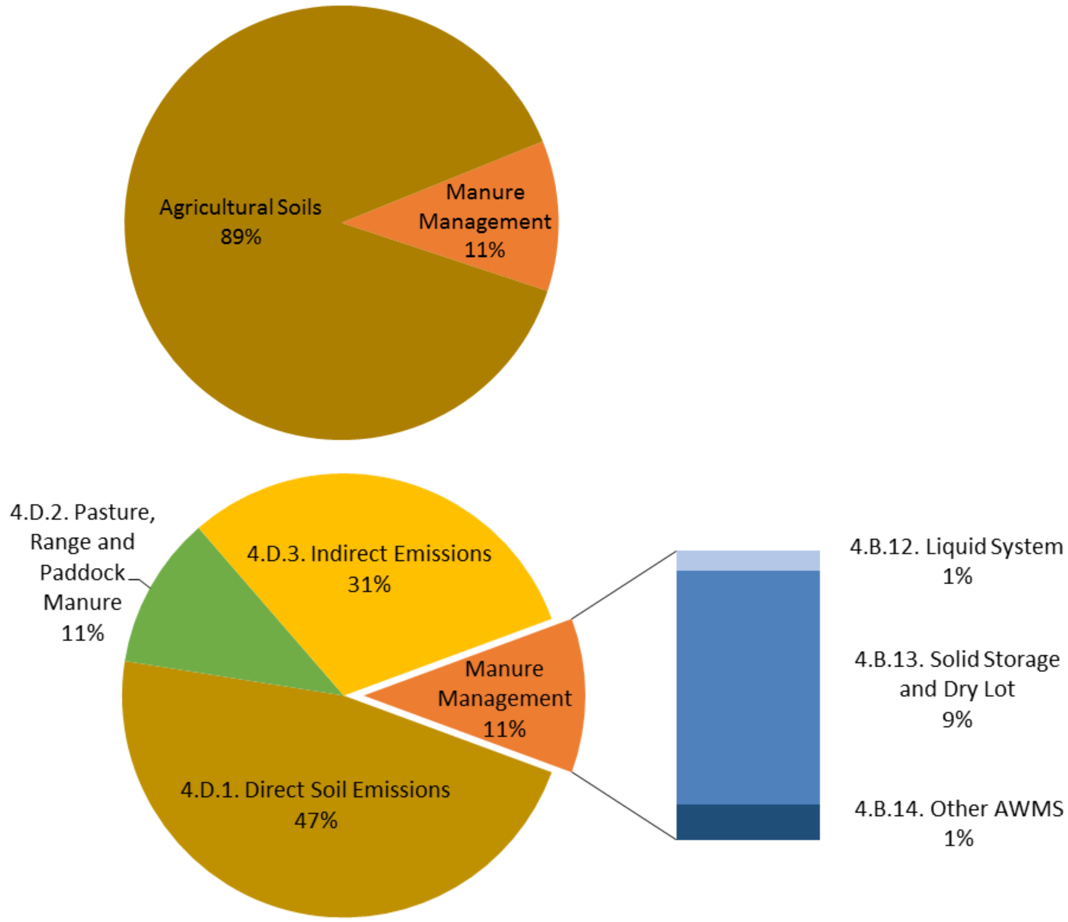
Figure 15: Breakdown of methane emissions in the EU-28, 2012



Note on the source categories for CH_4 emissions: 4.A = enteric fermentation; 4.B = manure management; 4.C = rice cultivation; 4.F = field burning of agricultural residues.
Source: EEA (2015).

The two (main) sources of agricultural N_2O emissions are manure management (11 % of EU-28 N_2O emissions) and agricultural soils (89 % of EU-28 N_2O emissions) (see Figure 16). The latter can be subdivided into (1) direct soil emissions from the application of mineral fertilisers and animal manure, and direct emissions from crop residues and the cultivation of histosols, (2) direct emissions from manure produced in the meadow during grazing, and (3) indirect soil emissions from nitrogen leaching and runoff, and from nitrogen deposition (see IPCC, 2006). Furthermore, field burning of agricultural residues releases some N_2O emissions, but they only account for 0.1 % of N_2O emissions in the EU-28 (see EEA, 2015).

Figure 16: Breakdown of nitrous oxide emissions in the EU-28, 2012



Note on the source categories for N_2O emissions: 4.B = manure management; 4.D = agricultural soils. Other AWMS = other animal waste management systems.
Source: EEA (2015).

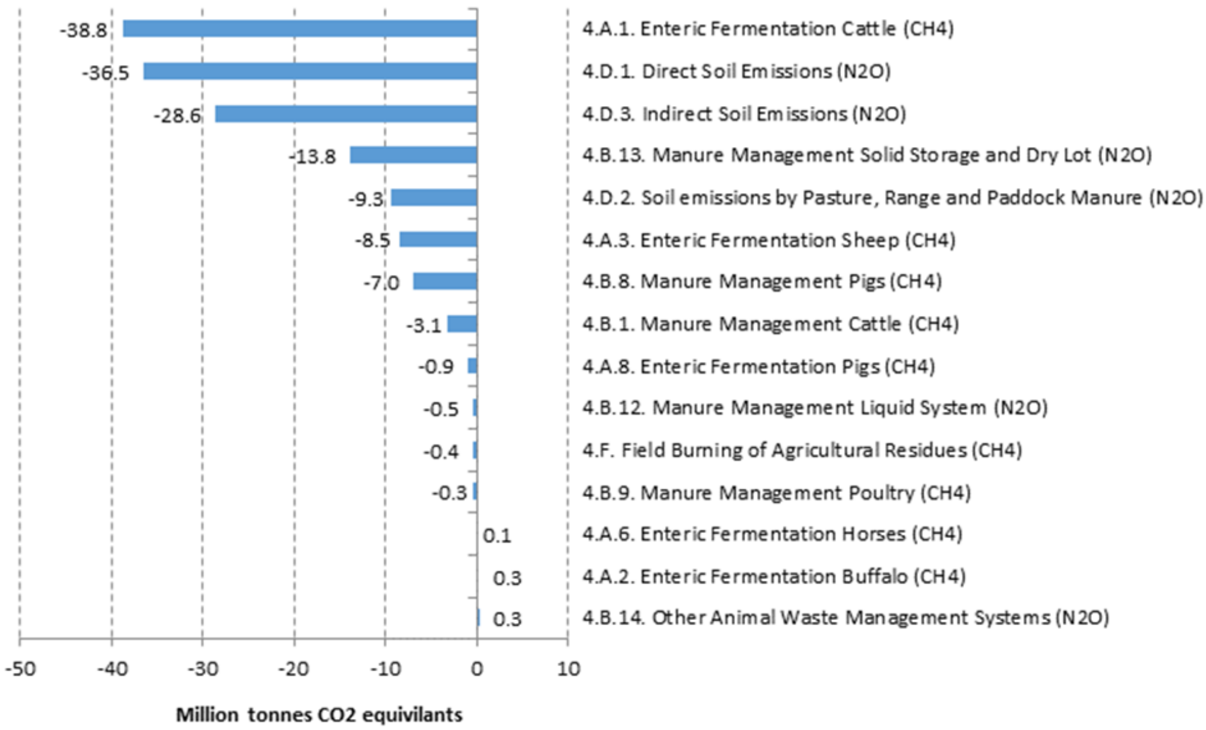
Looking at the historical developments of agricultural GHG emissions by key source categories reveals where the largest absolute decreases in CH_4 and N_2O emissions occurred in the EU-28 between 1990 and 2012 (see Figure 17).

The largest absolute reductions of CH_4 occurred in enteric fermentation in cattle, decreasing by 38.8 million tonnes of CO_2 equivalents (−24 %) between 1990 and 2012 at the EU-28 level, followed by a decrease of 8.5 million tonnes of CO_2 equivalents (−33 %) in enteric fermentation in sheep. The main driving force for CH_4 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 lead not only to decreases in emissions from enteric fermentation but also to decreased CH_4 emissions from the management of their manure. Thus, the reduction in CH_4 emissions can mainly be attributed to significant decreases in cattle numbers, which was influenced by the CAP (e.g. the milk quota and the introduction of decoupled direct payments), and to increases in animal productivity (i.e. milk and meat production) and the related improvements in the efficiency of feed use. In this context, the adjustments to agricultural production in the EU-N13 following the changes in the political and economic framework after 1990 have also been important.

The largest absolute reductions of N_2O emissions in the EU-28 occurred in soil emissions, with direct soil emissions decreasing by 36.5 million tonnes of CO_2 equivalents (−22 %) and indirect soil emissions by 26.6 million tonnes of CO_2 equivalents (−26 %) between

1990 and 2012. The main driving force of N_2O emissions from agricultural soils is the application of mineral nitrogen fertiliser and organic nitrogen from animal manure. Thus, the decrease in N_2O emissions from soils is mainly attributable to reduced use of mineral nitrogen fertilisers (which was the result of productivity increases but was also influenced by the successive CAP reforms) and decreases in the application of animal manure (as a direct effect of declining animal herds).

Figure 17: Largest absolute changes in GHG emissions by EU agriculture key source categories, 1990–2012 (million tonnes of CO_2 equivalents)



Source: EEA (2015).

3 Brief overview of the CAPRI modelling approach

For the quantitative assessment of mitigation policies in the agriculture sector, we employ the CAPRI modelling system (Britz and Witzke, 2014).[5] In this chapter, we present only a brief overview of the CAPRI model (section 3.1) and the general calculation of agricultural GHG emissions in CAPRI (section 3.2).[6] Details of the estimation of commodity-based emission factors for non-EU countries are given in section 3.3, while the modelling approach for endogenous technological GHG mitigation options, being an integral part of EcAMPA 2, is outlined in Chapter 4 of this report.

3.1 The CAPRI model

CAPRI is an economic large-scale comparative static agricultural sector model with a focus on the EU (at regional,[7] Member State and aggregated EU-28 levels), but covers 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 (i.e. 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[8] and a smooth simulation response[9] (see Pérez Dominguez et al., 2009; Britz and Witzke, 2014).

The market module consists of a spatial, global multi-commodity model for 47 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 (Armington, 1969). 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 (see Pérez Dominguez et al., 2009; Britz and Witzke, 2014).

3.2 Calculation of agricultural emissions

The CAPRI modelling system is adapted to calculate activity-based agricultural emission inventories. CAPRI is designed to capture 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 (see IPCC, 2006). The IPCC provides various methods for calculating a

[5] Detailed information on the CAPRI modelling system can also be found on the CAPRI model homepage (http://www.capri-model.org).

[6] Sections 3.1 and 3.2 are only slightly adjusted from the EcAMPA 1 report (Van Doorslaer et al., 2015).

[7] CAPRI uses NUTS 2 (Nomenclature of Territorial Units for Statistics, from Eurostat) as the regional level of disaggregation.

[8] With calibration, we determine the ability of the supply system to reproduce relevant information for specific markets. This can be (1) observed (i.e. statistics), (2) projected in the future (i.e. based on trends) or (3) provided by market experts (i.e. reference scenario).

[9] A smooth response is ensured through a cost function that is continuously differentiable, avoiding break points.

given emission flow. 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 (i.e. activity multiplied by default emission factor) and require fewer data and less 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, management or livestock characteristics. In CAPRI, a Tier 2 approach is generally used for the calculation of emissions. However, for activities for which the necessary underlying information is missing, a Tier 1 approach is used (e.g. rice cultivation). A more detailed description of the general calculation of agricultural emission inventories on activity level in CAPRI (i.e. without the inclusion of technological mitigation options) is given in Pérez Domínguez (2006) and in the GGELS report (Leip et al., 2010).

The reporting of emissions can take place by aggregating to the desired aggregation level. The output as given in the EcAMPA 2 report mimics the reporting on emissions by the EU to the UNFCCC (see Table 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

3.3 Calculation of emission leakage

GHG emissions are a global issue, and restricting the analysis of emissions to just one world region does not give the full picture of the mitigation effects of specific policies. In particular, the effects of changing trade patterns on global emissions is of relevance, as climate action in one region can give rise to emissions in another region (i.e. can lead to emission leakage). Emission leakage occurs when production shifts from an emission-constrained region to regions that do not have such (or have less stringent) constraints, so that formerly domestically produced products are substituted by less expensive imported products, leading to GHG emission increases in these other regions (Juergens et al., 2013, Pérez Domínguez and Fellmann, 2015). To measure emission leakage, additional data on the emissions of the rest of the world and their development are needed, which poses additional modelling challenges.

While EU emissions in CAPRI are based on specific agricultural activities (e.g. kilograms of CH_4 or N_2O emissions per animal 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. kilograms of CH_4 or N_2O per kilogram or litre of product).[10]

For the EU, activity-based emission intensities are derived from the activity for a given year. The underlying CAPRI supply model incorporates technological change (e.g. growth in yields, application of new technologies), allowing 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. However, this does not allow technological change (i.e. improved emission efficiency) to be incorporated for the rest of the world (see, for example, descriptions and discussions in Pérez Domínguez et al., 2012; Van Doorslaer et al., 2015). As the impacts are projected for several years (or decades) into the future, neglecting improved emission efficiency in non-EU countries could lead to an overestimation of emission leakage. To solve this, trend functions are estimated for the emission intensities in the rest of the world (see Annex 5). However, the model still does not incorporate the possibility of other world regions adopting mitigation technologies, and, therefore, estimates of emission leakage should still be considered as an upper bound.

For scenario analysis, the emission factors per commodity previously estimated for each non-EU region are multiplied with production to calculate the 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, GHG emission leakage is measured as the ratio of the total amount of increased emissions in non-EU regions to the emission mitigation effort in the EU.

[10] For example, pig breeding and pig fattening are activities in the EU (i.e. supply model of CAPRI), while pork is traded between 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).

4 Technological GHG emission mitigation options

Within the EcAMPA 1 study, the CAPRI modelling system was improved by implementing some specific endogenous GHG mitigation technologies. However, only a preliminary set of technologies was considered: community- and farm-scale anaerobic digestion, nitrification inhibitors, timing of fertilisation, precision farming, and changes in the composition of animal diets. For the underlying assumptions of these technologies (e.g. costs, mitigation potential and rate of adoption), the GAINS[11] database was mainly used (GAINS, 2013; Höglund-Isaksson et al., 2013).

One of the major improvements of EcAMPA 2 was the incorporation of more endogenous technological GHG mitigation options into CAPRI. To identify which technologies and management practices to consider, a workshop on 'Technological GHG emission mitigation options in agriculture' was jointly organised by the JRC and DG AGRI, in close collaboration with the Directorate-General for Climate Action (DG CLIMA). The specific aims of the workshop were the following:

- to have an open discussion about the different technological mitigation options that the European farming sector could consider in the medium to long term (i.e. years 2030 and 2050) to reduce GHG emissions;
- to discuss the potential uptake of these mitigation technologies versus a business-as-usual situation, their specific contributions to a reduction of emissions from agriculture and the additional costs incurred by the sector in their adoption;
- to reflect on the uncertainties attached to these options and the cross-links to other overall objectives such as food security and social, economic and environmental sustainability;
- to agree on a priority list of technologies to be used in economic models (e.g. CAPRI) for scenario and impact analysis.

The workshop was held on the 17 April 2015 in Seville (Spain) and brought together, as well as European Commission staff, external experts from a wide range of institutions, institutes and universities, such as the Food and Agriculture Organization (FAO), the International Institute for Applied Systems Analysis (IIASA), Teagasc (The Irish Agriculture and Food Development Authority), INRA (The French National Institute for Agricultural Research), Wageningen University, the Swedish University of Agricultural Science, Aarhus University, Scotland's Rural College, and the German Association for Technology and Structure in Agriculture (KTBL). The workshop, together with recent modelling efforts with CAPRI (within the EcAMPA 1 and AnimalChange[12] projects), built the foundation for the selection and implementation of the technological GHG emission mitigation options in EcAMPA 2.

In this chapter, a brief description of the technological GHG mitigation options considered in the study is first presented (section 4.1). After some general remarks on the (non-) adoption of technologies by farmers (section 4.2), the methodology of modelling costs and uptake of mitigation technologies in CAPRI is outlined (section 4.3).

4.1 Description and underlying assumptions of the technological GHG mitigation options considered

In this section, we briefly describe the technologies and management options considered in EcAMPA 2, and summarise the major assumptions taken in the modelling approach

[11] GAINS is short for 'Greenhouse Gas and Air Pollution Interactions and Synergies', and is a model describing the evolution of various pollutants and their mitigation options; it was developed by the International Institute for Applied Systems Analysis (IIASA; see http://gains.iiasa.ac.at/).
[12] See http://www.animalchange.eu/.

with regard to the mitigation potential etc. of the options. For the underlying assumptions, we rely mainly on GAINS data from 2013 (GAINS, 2013; Höglund-Isaksson et al., 2013) and its updated version of 2015 (GAINS, 2015; Höglund-Isaksson, 2015; Winiwarter and Sajeev, 2015), as well as on information collected within the AnimalChange EU-funded project (see Mottet et al., 2015).

Technological GHG mitigation options considered in all scenarios

1. Anaerobic digestion: farm scale

Anaerobic digestion (AD) is the microbiological conversion of organic matter in the absence of oxygen. When this process happens in a sealed tank (i.e. anaerobic digester), biogas is produced (i.e. a mixture of about 50–75 % CH_4, 25–45 % CO_2 and traces of other gases) and can be used to generate electricity, heat and/or vehicle fuel (Holm-Nielsen et al., 2009; FNR, 2013). A by-product of the AD process is digestate, a nutrient-rich substance that is usually used as fertiliser (Möller and Müller, 2012).

Many different raw materials are used as feedstock for AD, ranging from manure, harvest residues and dedicated energy crops from agriculture, to organic waste products from the food industry and households. Manure actually has a rather low biogas yield potential, which is why crop material and organic waste are often used as co-substrate to increase the yield of the biogas and make the AD plant more economically viable (Holm-Nielsen et al., 2009; Weiland, 2010; Seppälä et al., 2013; Kalamaras and Kotsopoulos, 2014).

AD technology is considered to have several environmental benefits. Apart from being a source of renewable energy, AD is a technology that has proven to be especially effective for reducing GHG emissions from livestock manure, particularly because it can considerably reduce CH_4 emissions from stored manure. AD also reduces N_2O emissions from livestock slurries (Clemens et al., 2006; Massé et al., 2011; Petersen and Sommer, 2011; Petersen et al., 2013).

For modelling AD, we follow the assumptions used in the AnimalChange project (AnimalChange, 2015), assuming that farms with more than 200 livestock units (LSU) can use AD as a technological option to mitigate manure emissions from livestock. Information on LSU has been taken from the EU farm structure survey (Eurostat, 2014).[13] In the pre-digester phase of the process, CH_4 losses of 25 % are assumed for liquid systems not including natural crust cover. Leaching losses during the digester phase are assumed to be 3 %. CH_4 yield, revenues and CO_2 savings from reduced burning of fossil fuels are calculated based on the following assumptions (see Mottet et al., 2015):

- pre-digester storage CO_2 loss rate: 2 %
- pre-digester storage CH_4 loss rate: 25 %
- CH_4 conversion factor of the digester: 85 %
- CH_4 leakage in the digester (% of CH_4 produced): 3 %
- CH_4 density: 0.67 kg/m^3
- energy content of CH_4: 55 MJ/kg
- energy conversion factor of CH_4: 277.8 kWh/GJ
- efficiency of heat generation: 40 %
- heat used in the AD plant (% of the heat produced): 9 %
- heat sold on the market: 30 %

[13] In the Eurostat survey, only the category 100–500 LSU is available. We therefore simply divided the category 100–500 LSU linearly. Thus, if there are, for example, 100 animals in the category 100–500 LSU, then one-quarter, or 25, are allocated to the group 100–200 LSU and three-quarters, or 75, are allocated to the group of 200–500 LSU. This is a simplification and probably not accurate because of the asymmetric distribution. This simplification might be changed in the future, but it was not possible to do so within EcAMPA 2.

- efficiency of electricity generation: 36 %
- electricity used in the AD plant (% of the electricity produced): 12 %
- emission intensity of heating: 0.26 kg CO_2/kWh
- emission intensity of electricity: 0.33 kg CO_2/kWh
- heat price: national values based on PRIMES estimates (provided by IIASA)
- electricity price: national values based on PRIMES estimates (provided by IIASA).

2. Better timing of fertilisation

Better timing of fertilisation means that the crop need/uptake and the applying of fertiliser and manure are more in line with each other. A timely application of fertilisers, especially nitrogenous fertilisers, has several beneficial effects for the environment. When fertilisers are applied in the autumn but crops are planted only in the spring, considerable amounts of nitrogen can be lost and, therefore, transformed into GHGs before the crops can use it for plant growth. The magnitude of the fertiliser losses (some of which occur as N_2O emissions to the atmosphere) due to untimely fertiliser application depends on a number of field conditions, such as soil characteristics, weather variables and farm management factors (e.g. placement and form of fertiliser, rotation or tillage system). While appropriate timing of fertiliser application involves costs for the farmers (e.g. increased management costs as a result of more frequent soil analyses, and splitting of the application of fertilisers), it can also lead to higher yields and/or lower fertiliser requirements (Hoeft et al., 2000).

This measure is economically dominated by Variable Rate Technology (VRT) according to the latest literature review by GAINS, as it achieves lower emission savings at higher costs. Therefore, coefficients for better timing of fertiliser application have not been updated in the GAINS. However, because in EcAMPA 2 we use different data for VRT (see 'Variable Rate Technology' below), this measure can still play a role. With respect to the underlying assumptions, the settings from GAINS (2013) are kept (i.e. the same ones already used in the EcAMPA 1 study; see Van Doorslaer et al., 2015).

With the exception of the scenario assuming more rapid technological development, the theoretical emission reduction potential of the mitigation option 'timing of fertilisation' is restricted by the regional over-fertilisation factors [14] estimated in CAPRI. For more information on how this restriction works, please see Annex 2, 'Restriction of fertiliser measures'.

3. Nitrification inhibitors

Nitrification is a natural process occurring in soils, converting ammonium to nitrite and then to nitrate. Nitrification inhibitors (NI) can be applied to slow down the transformation of ammonium into other forms that result in nitrogen losses and have adverse effects on the environment. NI are chemical compounds that delay bacterial oxidation of the ammonium ion by depressing the metabolism of *Nitrosomonas* bacteria over a certain time period. These bacteria are responsible for the transformation of ammonium into nitrite (NO_2); a second group of bacteria (*Nitrobacter*) then converts nitrite to nitrate (NO_3). The objective of using NI is to control leaching of nitrate by keeping nitrogen in the ammonia form for a longer time, preventing denitrification of nitrate and reducing N_2O emissions caused by nitrification and denitrification. Thus, via NI, crops have a better opportunity to absorb nitrate, which increases nitrogen-use efficiency and at the same time reduces N_2O emissions from mineral fertilisers (see, for example, Nelson and Huber, 2001; Weiske, 2006; Snyder et al., 2009; Akiyama et al., 2010; Delgado and Follett, 2010; Snyder et al., 2014; Lam et al., 2015; Ruser and Schulz, 2015).

[14] Over-fertilisation is when the fertiliser is applied in excess of the actual crop need. Over-fertilisation factors are estimated in CAPRI on a regional basis (i.e. grouping all crop production systems in a NUTS 2 region).

During the workshop in Seville, it was highlighted that NI could indeed be a powerful tool to decrease N_2O emissions. However, it was also pointed out that, even though they are applied and accepted in many countries such as the USA, there is still some discussion about their application in other world regions, due to possible negative health or environmental side effects, such as the appearance of traces in dairy products (e.g. the case of dicyandiamide being detected in New Zealand dairy products; OECD, 2013). In addition, the effectiveness of NI depends on environmental factors such as temperature, soil moisture, etc., and the inhibitors sometimes seem to easily leach out of the rooting zone, which also lowers the effectiveness of the inhibitor (see Akiyama et al., 2010). As an upper limit for the application, we took the national share of urea (based on MITERRA), plus the percentage of nitrogen applied as ammonium (100 % of ammonium sulphates and phosphates, 50 % of ammonium nitrates and NPK fertiliser (i.e. fertilisers providing nitrogen, phosphorus and potassium)).

Apart from this upper limit on the eligible area for NI, we followed the updated GAINS (2015) assumptions: an N_2O emission reduction of 34 % was assumed for the use of NI, with costs of EUR 86/tonne nitrogen. In GAINS (2015), it is also assumed that NI can be applied to manure to the same extent and the same cost as to mineral fertiliser (i.e. a 34 % reduction of N_2O emissions can be achieved at a cost of EUR 86/tonne nitrogen applied). However, literature and empirical evidence on the effectiveness of NI to reduce N_2O emissions related to manure application are rather scarce compared with mineral fertiliser applications. There seems to be good potential for the use of NI also in the context of manure application; however, the effectiveness depends on many factors (among others, a thorough mixing of the fertiliser with the NI, along with the time and form of manure application to the field). Therefore, it is difficult to achieve estimates of potential emission reduction effects and other impacts related to the use of NI with manure application, which is why in EcAMPA 2 NI are not applicable for the reduction of emissions from applied manure (i.e. we consider NI only to be used for mineral fertiliser application).

With the exception of the scenario assuming more rapid technological development, the theoretical emission reduction potential of the mitigation option ‘nitrification inhibitors’ is restricted by the regional over-fertilisation factors estimated in CAPRI. For more information on how this restriction works, please see Annex 2, ‘Restriction of fertiliser measures’.

4. Precision farming

Precision agriculture can generally be applied to both crop and livestock production. However, in EcAMPA 2 we refer only to its application to crop production, considering it to be ‘an information and technology-based crop management system to identify, analyse, and manage spatial and temporal variability within fields’ (Heimlich, 2003). Thus, precision farming is a management concept that is based on observing, measuring and responding to inter- and intra-field variability in crops. Precision farming incorporates several technological tools, including VRT, remote sensing technologies, Global Positioning Systems (GPS) and geographical information systems (GIS) that should all help to apply inputs and machinery more precisely. The goal of precision farming is optimising returns on inputs while preserving resources. As this managerial system enables the farmer to, among other things, make better use of fertilisers and fuel use, it also directly contributes to reducing GHG emissions (Auernhammer, 2001; Du et al., 2008; Mulla, 2013; Kloepfer et al., 2015).

In GAINS (2015), and consequently in CAPRI, all the different technological tools that constitute precision farming (VRT, remote sensing technologies, GPS and GIS) are merged into one composite measure called ‘precision farming’. Only VRT is separated, as it is considered to be a single precision farming technology of wider application and lower implementation costs (see ‘Variable Rate Technology’ below). Regarding the GHG emissions related to precision farming, only the reduction in N_2O emissions is taken into account in the CAPRI modelling system at this point. For the inclusion of precision farming as a mitigation technology option in EcAMPA 2, we followed the assumptions of the updated GAINS (2015) data and assumed a potential reduction of N_2O emissions of 36 % (see GAINS, 2015; Winiwarter and Sajeev, 2015).

With the exception of the scenario assuming more rapid technological development, the theoretical emission reduction potential of the mitigation option 'precision farming' is restricted by the regional over-fertilisation factors estimated in CAPRI (see footnote 14). For more information on how this restriction works, please see Annex 2, 'Restriction of fertiliser measures'.

5. Variable Rate Technology

VRT is a subset of precision farming. As mentioned above, crop yield potential can vary considerably within a field, and VRT is a method to control this variability on a field by allowing variable map- and sensor-based rates of fertiliser and chemical application, seeding and tillage within a field (Du et al., 2008; Lawes and Robertson, 2011; Kloepfer et al., 2015). In EcAMPA 2, with VRT we refer to a technology that is used to apply a site-specific and variable application of fertiliser (i.e. the rate of fertiliser application is based on the needs of the precise location). This optimises the fertiliser application.

In contrast to the other measures related to fertiliser use (i.e. timing of fertilisation, nitrification inhibitors, precision farming), for VRT we did not follow the assumptions from GAINS (2015). The assumptions of GAINS (2015) were considered as not being adequate to be applied to the EU, as they are solely based on studies related to US agriculture, where the average farm size is considerably larger than in the EU. Therefore, we based our calculations on assumptions and data provided by KTBL (2015), which in turn used EU literature for its calculations. According to Flessa et al. (2012), mineral fertiliser application might be reduced by 2–20 kg nitrogen/ha with the use of VRT. For a default mineral fertiliser application of 140 kg/ha, this corresponds to a reduction of 1.5–15 %. KTBL (2015) suggests that these variations might be related to the particular subset of VRT applied, and proposed an assumed a reduction of 5 kg nitrogen/ha using only the nitrogen sensor, 10 kg nitrogen/ha combining this with a map overlay and GPS, and 20 kg nitrogen/ha if equipment for modern data management is added (i.e. 'full set'). The reduction factors are 3.6 %, 7.1 % and 14.3 %, respectively.

The baseline assumption in CAPRI is a 6 % reduction of nitrogen application, which follows the observed general trend in European agriculture towards more efficient use of nitrogen. In accordance with GAINS we, therefore, have to deduct the trend from the reduction factors reported by KTBL.[15] As a consequence, only the third option ('full set' of VRT) guarantees a sufficient reduction (8.8 % or 12.34 kg nitrogen/ha) to be effectively considered in our analysis.

The cost information for VRT is taken from the FP7 project FutureFarm,[16] which suggests investment costs of around EUR 50 000 for the above-mentioned third option ('full set' of VRT) (Tavella et al., 2010). With a lifetime of 10 years, a farm size of 100 ha and a discount rate of 5 %, we get annual investment costs of EUR 64.75/ha. This is equivalent to costs of EUR 5.25/kg nitrogen saved (i.e. EUR 64.75/12.34 kg) or EUR 462.52/tonne nitrogen applied (i.e. EUR 5.25 * 1 000 * 0.088). This cost value has to be corrected, as the application of VRT also saves costs owing to the lower fertilisation rate (0.088 * price per tonne of nitrogen). The correction is done endogenously in CAPRI, depending on the fertiliser price. For a price of EUR 1 111/tonne nitrogen (i.e. price suggested by KTBL), we would get net costs of EUR 364.6/tonne nitrogen applied, which is more than ten times higher than the value of EUR 33 from GAINS. As mentioned above, the difference might be driven by different assumptions on the farm size.[17]

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[15] [1 – (1 – *red*)/(1 – 0.06)], where *red* is the above-mentioned reduction factor.
[16] See http://www.futurefarm.eu/
[17] It has to be noted that it would be preferable to link the cost curve for VRT application directly to the farm size distribution, as was done for anaerobic digestion. Unfortunately, the given timeframe

With the exception of the scenario assuming more rapid technological development, the theoretical emission reduction potential of the mitigation option 'VRT' is restricted by the regional over-fertilisation factors estimated in CAPRI. For more information on how this restriction works, please see Annex 2, 'Restriction of fertiliser measures'.

6. Increasing legume share on temporary grassland

The positive effects on GHG emissions of increasing the share of legumes on temporary grassland are twofold. First, it improves the soil carbon content and, second, it reduces the need for nitrogen fertiliser application through the capacity of these crops to fix nitrogen in the roots. Following the assumptions taken in the AnimalChange project, the share of legumes on temporary grassland in the base year[18] is kept constant over time for each Member State, based on Helming et al. (2014). It is assumed that the share of legumes on temporary grassland can be increased to a maximum of 20 %, which is equivalent to a nitrogen fixation rate of 15 %. The biological nitrogen fixation processes lead to a reduction in fertiliser use.

7. Rice measures

The technological mitigation options targeting emissions from rice cultivation are of rather minor importance in the EU-28, since rice cultivation accounts for only 0.6 % of total agricultural GHG emissions. Nonetheless, these options may help to reduce agricultural emissions in some EU regions. The current implementation is based on the updated literature review by the GAINS team (Höglund-Isaksson, 2015). Compared with previous GAINS applications, the choice set has been simplified such that there is currently only one mitigation option that combines intermittent aeration, selecting specific rice varieties and sulphur application. Otherwise, the parameters and cost assumptions have been maintained in GAINS since 2013 and CAPRI has adopted these coefficients.

8. Fallowing histosols

Histosols are soils consisting primarily of organic materials. 'Histosols' is the effective international standard name for organic soils. Other names include peat soils and muck soils, and histosols appear in national soil classifications under other names such as Moore (Germany) and organosols (Australia). The definition of what makes a soil a histosol is complex, referring to the thicknesses of soil layers, the organic content of these layers and their origin, underlying material, clay content and annual period of water saturation (Couwenberg, 2011). Guidelines for the classification of organic (peat) soils are given in IPCC (2006).

Histosols (peatlands) are very efficient carbon sinks. They contain high densities of carbon accumulated over a long time period because its decomposition is suppressed by the absence of oxygen under flooded conditions (Smith et al., 2007). To use organic (peat) soils for crop production, they need to be drained. This drainage leads to aeration and subsequent decomposition of the peat, which results in a substantial release of CO_2 and N_2O emissions. Thus, restoration/fallowing of histosols is considered an effective technological GHG mitigation option (Smith et al., 2007; Joosten, 2009; Couwenberg, 2011; Roeder and Osterburg, 2012; Reed et al., 2013).

in this project did not allow this approach, and we had to decide for one (average) farm size to determine the costs in order to fit in the default cost calibration. We think that, for the EU, a 100 ha farm corresponds better to this average farm size than a 500 ha farm. The GAINS numbers are based on US studies with implicit average farm sizes significantly higher than 100 ha, which was the reason to take estimates from KTBL and FutureFarm. However, the current solution is not optimal, which is even more true, as in reality the equipment might be bought not only by single farms but also by machinery rings.

[18] The base year refers to the last year(s) for which we have a full dataset to run the CAPRI model.

In EcAMPA 2, the mitigation option of fallowing histosols is considered by also setting aside a certain proportion of the agricultural area in each Member State. At a level of 100 % implementation of this mitigation option, the additional idle land equals the total histosols area in a region. This means that, for example, in Finland, a 100 % implementation rate of the mitigation option 'fallowing histosols' may result in idle land equal to 10 % of the utilisable agricultural area (UAA), whereas, in Spain, this is perhaps 0.5 % of the UAA. Direct costs of this measure are the opportunity cost of land use (i.e. concurrent uses). However, there are additional indirect costs faced by the farmers to achieve a 100 % implementation rate of this measure (e.g. transaction costs linked to regional land regulation).

Currently, only the effects on N_2O are considered in the GHG accounting of EcAMPA 2. The carbon sequestration effect still needs to be added, as it is relevant for the LULUCF sector. Therefore, the benefits regarding total GHG emission mitigation of the measure are currently strongly underestimated.

9. Low nitrogen feed

Low nitrogen feed (LNF) is a measure that aims to reduce ammonia (NH_3) emissions from livestock. Essentially, a lower nitrogen content of feed reduces nitrogen excretion by animals and, consequently, NH_3 emissions. However, there are positive cross-over effects with regard to N_2O and CH_4 emissions. There is a direct linear relationship between the input of dietary nitrogen and the nitrogen excretion via urine and faeces. On average, livestock excrete about two-thirds of the dietary nitrogen intake via urine and faeces, and only one-third is transformed into the protein of animal products. N_2O emissions depend on the amount of nitrogen excreted by animals. Thus, if a lower nitrogen content of the fodder reduces nitrogen excretion, this also positively affects the N_2O emissions from livestock (Kirchgessner et al., 1994; Weiske, 2006; Luo et al., 2010). Regarding CH_4, it is not clear in which direction a reduction of the nitrogen content of the fodder would affect emissions. LNF might affect feed intake and digestibility rate, which in turn can affect the level of CH_4 emissions from enteric fermentation and from manure management.

Following the approach taken in the AnimalChange project, only the reduction of N_2O emissions is considered for LNF in EcAMPA 2. This technological mitigation option is intended to reduce the crude protein (CRPR) intake of animals, assuming that the measure achieves a maximum reduction of 50 % of CRPR over-supply. Furthermore, it is assumed that the option can be applied to 100 % of monogastrics, 100 % of the indoor time of dairy cows and 50 % of the indoor time of other ruminants. As N_2O emissions are directly related to nitrogen excretion, and the CAPRI model derives nitrogen excretion directly from CRPR intake and nitrogen retention, there are no other assumptions needed to quantify emission reductions from this measure in CAPRI (Mottet et al., 2015).

10. Feed additives to reduce methane emissions from enteric fermentation: linseed

Supplementing animal diets with lipids (i.e. vegetable oils or animal fats) is used to increase the energy content of the diet and to enhance energy utilisation by lowering dry matter intake and improving digestion. The combination of decreased dry matter intake and (potentially) maintained or increased (milk) production improves feed efficiency and results in decreased CH_4 emissions from cattle. One of the most efficient dietary lipids is linseed. However, the effectiveness of feeding linseed for decreasing enteric CH_4 emissions depends on the feed mix. Furthermore, feeding too much linseed can have negative effects on the overall diet digestibility (Martin et al., 2008; Chung et al., 2011; Eugène et al., 2011; Grainger and Beauchermin, 2011; Nguyen et al., 2012; Marette and Millet, 2014; Van Middelaar et al., 2014).

In EcAMPA 2, we follow the assumptions taken in the AnimalChange project, assuming that the emission mitigation option of feeding linseed can be applied to 100 % of dairy cows, but to only 50 % of other cattle categories, as the intake has to be constant, which can be better controlled for dairy cows. The feeding of linseed is limited to a maximum of 5 % total fat in dry matter intake. Accordingly, the feed intake of linseed depends on the fat content of the diet, which is calculated endogenously in CAPRI and varies between regions. It is assumed that, for each per cent of fat added, a 5 % reduction of CH_4 emissions from enteric fermentation is achieved (Mottet et al., 2015).

11. Genetic improvements: increasing milk yields of dairy cows

A general genetic selection of individual animals with lower than average CH_4 emissions is already possible at present, but to really have a lasting GHG mitigating effect requires that the host animal controls its microflora, that the trait is heritable and that the effect is persistent. Furthermore, a selection for low CH_4-producing animals might come at the cost of productivity and fertility (i.e. with adverse effects on total GHG emissions per kilogram of meat or milk). Accordingly, intermediate GHG reductions through genetic improvements, aimed directly at reduced CH_4 emissions per ruminant, are very uncertain (Eckard et al., 2010; Cottle et al., 2011; Axelsson, 2013; Clark, 2013; Hristov et al., 2013; Berglund, 2015).

At the workshop on technological GHG mitigation options in Seville, experts pointed out that breeding for enhanced productivity with maintained animal health and fertility is seen as the most effective solution to reduce CH_4 emissions per dairy cow (somewhat smaller for non-dairy cattle and sheep). In the EU, there is actually already a broad breeding goal in the dairy sector, which is included in the dairy market medium-term prospects. However, average milk yields are quite diverse across EU Member States and actually significantly below average in some countries. Therefore, in EcAMPA 2, we included the option of genetic improvements with regard to increasing milk yields per cow. The increase in milk yield implies reductions of GHG emissions per kilogram of milk.

In CAPRI, we assume that breeding achieves some improvements in milk yields of dairy cows in those countries below the EU-28 'top group', which is defined in the model as Denmark, Finland, Sweden and Portugal. We take the simple average of the milk yields of these four countries to define the 'top yield' (about 10 tonnes in 2030). Other regions are catching up with the top group according to:

yield_new = yield_old + p_ghgTechMYld * (yield_top – yield_old)

Note that setting p_ghgTechMYld as 1 would imply that yields should increase in any other region to the yields of the top group (i.e. 10 tonnes/cow).

In the standard case, we set p_ghgTechMYld as 0.2, while under the scenario assuming full potential of technological mitigation options, this was increased to 0.3. Thus, for example, under the full potential assumption and if the option 'breeding for higher milk yields' was implemented at a rate of 100 %, the following increase in milk yield would be achieved in Romania:

4.8 tonnes + 0.3 * (10.0 tonnes – 4.8 tonnes) = 6.4 tonnes, where average milk yields increase from 4.8 tonnes in the reference scenario in 2030 (in 2010: 3.5 tonnes) to 6.4 tonnes/cow. In other words, while in Romania milk yields are projected to increase in the reference scenario by 2030 compared with 2010 by 25 %, a full uptake of the option 'breeding for higher milk yields' in the 'full technological potential' scenario would result in an increase of Romanian milk yields of almost 90 % by 2030 compared with 2010.

The assumed accounting costs are 20 % of the additional revenue for genetic improvements of dairy performance (i.e. the increase in milk yield multiplied by the milk price in the reference run), but at least EUR 20 per cow. The principle of linking the cost to the economic benefit favours an EU-wide application that was considered of interest and also realistic. Given that the absolute yield potential may differ across regions, a uniform cost assumption, perhaps with some gross domestic product (GDP) adjustment, would have resulted in vastly diverging adoption rates across regions from 0 to 100 %. However, this was considered implausible, as the administrators of any breeding programme will have to make sure that it is attractive to farmers.

It is important to note that a frequent finding of testing different parameter settings for this measure is that the decline in milk and dairy prices and in the EU dairy herd is often not sufficiently large to counteract the increase in emissions induced by higher milk yields (please note that higher milk yields also mean higher emissions per head, even though emissions per litre of milk produced may be reduced). The measure, therefore, might not appear to be the most beneficial one of the EcAMPA 2 selection of mitigation technologies in terms of emission mitigation potential.

12. Genetic improvements: increasing ruminant feed efficiency

A further mitigation option related to genetic improvements is increasing ruminant feed efficiency. In EcAMPA 2, we assume that the main effect (at a 100 % implementation rate) is a 10 % reduction in energy need of non-dairy ruminants, as this should reflect breeding for lower CH_4 losses. In addition, we assume that crude protein need would also decline by 5 % for two reasons: (1) such a decrease in crude protein need may be practically unavoidable if efficiency gains in energy use from breeding also extend to protein, and (2) in test runs with the model, we saw that an exclusive reduction of energy need by 10 % creates strong incentives for changes in the feed mix towards protein-rich feed that appeared implausible and sometimes even infeasible, in particular in regions that strongly rely on grass.

The feed efficiency gains reduce feed intake, which automatically reduces CH_4 emissions in the case of cattle (Tier 2 calculation). For sheep (Tier 1 in CAPRI), we included a special reduction factor that also reduced CH_4 from enteric fermentation by 10 % if the measure is fully implemented. This different technical treatment is necessary because the accounting is simplified for sheep in CAPRI, but the key effect (10 % saving) is the same, as CH_4 emissions are a loss of feed energy. The order of magnitude (10 %) is based on the recent literature review by the GAINS team (Höglund-Isaksson, 2015). In EcAMPA 2, it is assumed that the breeding programme targeting feed efficiency focuses on cattle in the production chain for beef, but excludes dairy cows and also breeding heifers, as they are targeted by the other breeding programme, which aims to improve milk yields.

With respect to costs, we assume accounting costs of 10 % of the estimated savings in feed costs, but at least EUR 2 per animal (which is considered low when the animals are sheep or calves). The savings have been estimated as the percentage reduction in energy requirements multiplied by the value of feed use in the reference run.

Technological mitigation options considered only in a scenario assuming more rapid technological development

It is assumed that the 12 mitigation technologies mentioned above will be commercially available in the projection year 2030. However, there are other mitigation technologies for which it is rather uncertain whether or not they will become commercially available in such a short time period. In EcAMPA 2, we run a scenario where we assume a more rapid development of emission mitigation technologies. In this scenario, in addition to the 12 options mentioned above, we assume that two more mitigation technologies are available, namely nitrate as a feed additive to reduce CH_4 emissions from enteric fermentation, and vaccination against methanogenic bacteria in the rumen.

13. Feed additives to reduce methane emissions from enteric fermentation: nitrate

Bacteria from the rumen are able to use nitrate as alternative electron acceptors for hydrogen, which reduces CH_4 production. Thus, using nitrate as a feed additive can reduce CH_4 emissions from enteric fermentation. The CH_4 reduction potential seems to be quite high, but it requires a careful dosage to avoid negative health effects to the livestock (Cottle et al., 2011; Hristov et al., 2013; Bannink, 2015).

Following the AnimalChange approach, we assume that nitrate feeding can be applied in the EU-28 to 100 % of dairy cows and to 50 % of fattening cattle and replacement heifers (i.e. for the time they spent in the stable). Furthermore, it is assumed that, for dairy cows, adding nitrate to the feed is limited to the time of lactation (about 10 months/year). The intake of nitrate is limited to a maximum of 1.5 % of total dry matter intake. For each per cent of nitrate added, CH_4 emissions from enteric fermentation are assumed to decline by 10 % (i.e. the maximum reduction amounts to 15 %). Furthermore, as dietary nitrate increases the excretion of nitrogen, an equivalent reduction of crude protein intake of 0.42 % for 1.5 % nitrate is assumed (Mottet et al., 2015).

We assume that the two feed additives linseed and nitrate can be applied separately but also simultaneously.

14. Vaccination against methanogenic bacteria in the rumen

This technological mitigation option refers to vaccines that specifically target the CH_4-producing methanogens in the rumen. These vaccines are still in the development phase. They could have significant potential in extensive ruminant systems and, for example, the development of a vaccine against cell-surface proteins, which are common to a broad range of methanogen species, may improve the efficacy of vaccination as a CH_4 mitigation option. However, study results on vaccination against methanogenic bacteria in the rumen are rather inconsistent (Wright et al., 2004; McAllister and Newbold, 2008; Eckard et al., 2010; Hook et al., 2010). During the workshop in Seville, it was highlighted that further testing is needed before this option can be considered viable.

Nonetheless, we incorporated vaccination against methanogenic bacteria in the rumen as a technological mitigation option in EcAMPA 2. The assumptions on this option did not change in the updated GAINS (2015) compared with GAINS (2013) (see Höglund-Isaksson, 2015). Basically, GAINS assumes that vaccination against methanogenic bacteria reduces enteric fermentation of dairy and non-dairy cattle, as well as sheep, by 5 %. Furthermore, in GAINS, a cost of EUR 10 per animal per year is assumed for this technology. In EcAMPA 2, we followed these assumptions of GAINS. However, while in analyses with GAINS, vaccination is considered only from 2030 onwards, we assume that the technology could already be applied by 2030 in the scenario assuming more rapid technological development.

Some notes on other technologies not included in the EcAMPA 2 approach

In the following section, we provide some information about technological mitigation options that are not considered for EcAMPA 2.

Feed additives to reduce methane emissions from enteric fermentation: propionate precursors

Propionate precursors are organic acids such as malate and fumarate. Adding organic acids to the diet leads to a reduced production of CH_4 in the rumen, as the organic acids react in the rumen with hydrogen to produce propionate, thereby leaving less hydrogen available for CH_4 formation. The additive can be given directly to livestock fed indoors. However, the mitigation potential is sometimes questioned, and it is not clear if it is effective *in vivo* and it is unclear if they will really be commercially available by 2030 (Ungerfeld and Forster, 2011; Bannink, 2015). The doubts about propionate precursors have also been raised during the discussions in the workshop in Seville.

We have technically implemented propionate precursors as a mitigation option in CAPRI. However, in the discussion about which technologies to include in EcAMPA 2, it was decided not to include propionate precursors as a technology that could be applied by farmers by 2030.

Reduction of mineral fertiliser application on crops and grassland

This is an inexpensive measure, but might have rather small effects, as presented in EcAMPA 1. If included as a specific mitigation option in CAPRI, double counting should be avoided, as a certain reduction in fertiliser application is already assumed as part of the

CAPRI baseline (see the earlier comments on fertiliser timing). For these reasons, this measure has not been included as an extra technology option in EcAMPA 2; basically, it is considered only as a special form of measure targeting fertiliser use on grassland. Moreover, it may already be covered by the measures 'better timing of fertilisation', 'VRT' and 'precision farming', which are not limited to specific crops but assumed to be applicable to the whole agricultural area.

Sexed semen

The goal with gender-selected or sexed semen is to produce a calf of a specific sex. Sexed semen has been available for some years, and dairy producers can use it to obtain more (and better) heifer calves. More recently, sexed semen from beef bulls has also become commercially available.

This measure has not been implemented in EcAMPA 2 because of insufficient information on costs for an EU-wide application. A future implementation in CAPRI should be possible, but two caveats should be considered:

- It will require substantial testing, because CAPRI has a fixed male to female calves ratio, and relaxing this constraint would certainly limit the flexibility of the cattle sector, affecting dairy and meat markets in an important manner.
- Sexed semen will be a kind of efficiency enhancement measure that would certainly improve the competiveness of the EU cattle sector (and perhaps worldwide). These efficiency improvements might stimulate production to some extent, as female calves for the dairy sector might become a cheaper input. The emission saving effects will therefore be quite uncertain, in particular when looking solely at EU emissions.

Soil management in arable cropping (tillage and catch crops)

At the workshop in Seville, it was indicated that tillage effects are often mixed with other effects (e.g. changes in other techniques such as the introduction of catch crops). However, experts also pointed out that N_2O emissions are, on average, not particularly affected by soil tillage (i.e. in general, the GHG balance seems to be little affected by soil tillage). No-tillage management techniques might be more beneficial for soil quality than for GHG mitigation. Catch crops could be a promising measure in terms of soil management, reducing soil erosion and helping the soil to retain micronutrients, but its implementation in CAPRI has not been feasible so far.

An overview on the modelling approach taken in EcAMPA 2 with respect to the modelling of costs and revenues of technological GHG mitigation options is presented in Table 2.

Table 2: Overview on the modelling approach taken regarding technological GHG mitigation options

Technological mitigation option	Literature data provided on:			CAPRI endogenously calculates cost savings	CAPRI uses for calibration…	Gross cost is…	Net cost is…	Subsidies calculated as 80% of…	Cost reported as…
	Gross cost	… + revenues	… + cost savings						
Anaerobic digestion	x	x		No	Net cost	Endogenous calculation**	Gross cost minus revenues**	Gross cost	Net cost
Better fertilization timing Nitrification inhibitors Precision farming Variable Rate Technology (VRT)	x		x	Yes	Net cost	Literature net costs plus endogenous cost savings	Literature net costs corrected to be consistent with endogenous cost savings	Net cost	Net cost
Higher legume share on temporary grassland	x			Yes	Net cost	Literature	Literature minus endogenous cost savings	Gross cost	Net cost
Rice measures	x	x	x	No	Net cost	NA	Literature gross costs minus cost savings	Net cost	Net cost
Fallowing histosols	Assumed zero			Yes	Net cost	Zero	Endogenous (= forgone income)	Net cost	Net cost

Overview on the modelling approach taken regarding technological GHG mitigation options (continued)

Technological mitigation option	Literature data provided on:			CAPRI endogenously calculates cost savings	CAPRI uses for calibration…	Gross cost is…	Net cost is…	Subsidies calculated as 80% of…	Cost reported as…
	Gross cost	… + revenues	… + cost savings						
Low nitrogen feeding	x			Yes*	Net cost	Literature	95% of gross cost (endogenous cost savings not considered)	Net cost	Net cost
Feed additives: linseed Feed additives: nitrate	x			Yes*	Net cost	Literature	50% of gross cost (endogenous cost savings not considered!)	Net cost	Net cost
Genetic improvements: milk yields of dairy cows Genetic improvements increasing ruminant feed efficiency				No	Gross cost	% of gains from measure	Gross cost	Gross cost	Gross cost
Vaccination against methanogenic bacteria in the rumen	x			No	Gross cost	Literature	Gross cost	Gross costs	Gross costs

*Owing to the models' design, cost savings for the feed measures (i.e. reduced feed cost as animals eat less or other feed) cannot be allocated to specific measures. Therefore, net cost is assumed to be 50 % of total cost for feed additives, and a moderate mark up on feed cost for low nitrogen feeding has been chosen (5 %).

**Costs and revenues are calculated on the basis of manure and volatile solid production (endogenous variables in CAPRI) and the regional farm size structure.

4.2 Some general remarks on the (non-)adoption of technologies by farmers

As pointed out by Nowak (1992), there is a general agreement on the question of why farmers should adopt (new) production technologies. The universal narrative is that a (new) production technology is usually adopted by farmers if the technology is perceived as being in the farmers' best interests. Following this narrative, the adoption of environmentally friendly technologies is also included. For example, farmers would try avoiding soil degradation, as this may decrease the future production potential of the land. Likewise, it is generally in the farmer's best interest to adopt management technologies that are in accordance with environmental legislation, even if the reason may simply be to avoid being caught and fined for not complying. As for all other technologies, the narrative of 'perceived as being in the best interest of the farmer' also applies to the adoption of technological GHG emission mitigation options. The important question is which factors actually determine farmers' perception that adopting a certain technology is in their best interests.

The examination of factors influencing the adoption of technologies and management practices has been a focus of agricultural economics research for a long time (see, for example, Sunding and Zilberman, 2001; Knowler and Bradshaw, 2007; OECD, 2012). One of the first economists to analyse the adoption and diffusion of technological innovations in agriculture from an economic perspective was Griliches (1957). In his analysis, Griliches found that profitability was the largest determinant for the adoption of hybrid maize. Although many other 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 (see, for example, 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). In the following section, some of these other determinants are briefly highlighted.

Technologies that promise to be profitable will usually be more rapidly adopted if they do not require large capital investments or major adjustments in the management style of the farm. However, risk plays a role in a farmer's perception of net returns, which therefore also directly influences the adoption of a new production technology. Usually there is quite some uncertainty involved when switching to a new production technology or management practice, which may be related to both the handling and performance of the technology and the effect the technology may then really have on the farmer's net return. This uncertainty interacts with the random factors that affect agriculture (weather, etc.) and increases risk, making it likely that farmers will discount the expected benefits of adopting a new production technology. Thus, because of the discounting for the added risk, a new production technology and management practice may not be adopted by the farmer, even if it a priori is profitable (see, for example, Sunding and Zilberman, 2001; Marra et al., 2003;).

A frequently identified determining factor of technology adoption is farm size, with larger farms usually demonstrating a higher adoption rate and more rapid diffusion of new technologies (e.g. Just and Zilberman, 1983; Diederen et al., 2003; Roberts et al., 2004; Gillespie et al., 2007; Banerjee et al., 2008; Pruitt et al., 2012). There is also a relationship between the uptake of technologies and a farm operator's off-farm employment and off-farm income. Operators of large farms that are more dependent upon on-farm income are found to be more likely to adopt managerially intensive technologies such as precision farming (e.g. Caswell et al., 2001; Daberkow and McBride, 2003; Fernandez-Cornejo, 2009).

Technology adoption is also shown to be related to factors such as simplicity and flexibility of the technology (see, for example, Reichardt et al., 2009). Moreover, human capital characteristics such as age, education and experience represent other frequently identified factors influencing technology adoption (e.g. Caswell et al., 2001; Daberkow and McBride, 2003; Diederen et al., 2003; Roberts et al., 2004; Gillespie et al., 2007; Pruitt et al., 2012). In particular, education is often demonstrated to have a strong positive effect on the adoption of information-intensive technologies, for example exemplified by Caswell et al. (2001) in a study that analyses the adoption of agricultural production practices specifically relating to nutrient, pest, soil and water management across differing natural resource regions. Age, on the other hand, is often found to negatively affect the probability of technology adoption, which is, in many cases, related to shorter planning horizons of older farmers, who therefore have fewer incentives to change technology (e.g. El-Osta and Mishra, 2001; Roberts et al., 2004).

The answer to the question 'why do farmers adopt a production technology?' inherently also encompasses the answer to the question 'why do farmers not adopt a technology?'. Nonetheless, it is beneficial for the common understanding to also specifically highlight some of the reasons that lead to non-adoption of a technology. For this, we rely on an essay of Nowak (1992), who points out two basic reasons for non-adoption: the farmer is either unable or unwilling, with these two reasons not being mutually exclusive.

The reasons for being *unable to adopt* a technology can be manifold and comprise, among others, a lack of or missing information for a sound economic and agronomic decision; the technology is too difficult or complex to use; costs of the technology are too high (investment, variable cost or influence on net return); the farmer's planning horizon is too short relative to the time associated with recuperating the investment and learning costs of the new technology, or relative to the depreciation of the present technology used; and inadequate managerial skills.

The reasons for being *unwilling to adopt* a technology can also be manifold and comprise, among others, conflicts or inconsistencies in the information; poor applicability and irrelevance of the information (e.g. data from across the country may be judged as not meeting local conditions); the (new) technology does not fit the existing production system; the technology or management practice is inappropriate for the physical setting of the farm operation; a belief in traditional practices; and ignorance on the part of the farmer.

Being unable to adopt a production or management technique implies that the decision of not adopting is rational (i.e. perceived as 'correct'). Likewise, being unwilling to adopt a technique implies that the farmer is not convinced that the technology will work or is appropriate for the farm operation and, in this case, rejecting the adoption of the technology is, at least subjectively, also rational (see Nowak, 1992).

Box 1: (Non-)adoption of would-be win–win mitigation technologies by farmers

In an article in the journal *Nature Climate Change*, Moran et al. (2013) specifically address the issue of would-be win–win mitigation measures in the agricultural sector (i.e. measures that are supposed to reduce GHG emissions and save costs at the same time). In their article, Moran et al. highlight that marginal abatement costs indicating win–win mitigation measures often seem to oversimplify farmer motivation, because they usually focus only on profit maximisation and do not consider the reasons for non-adoption, as pointed out in the section above. Furthermore, transaction costs related to the use of mitigation technologies (learning, implementing, monitoring, verifying) are often poorly recorded (i.e. they 'remain largely unobserved by researchers identifying win–win' measures (Moran et al., 2013, p. 612)). This can occur especially in studies that are conducted under laboratory conditions or with limited experimental data. In addition, Moran et al. also point out that win–win options that are based on average values for the entire farm sector do not apply to all farms (i.e. they may disguise the fact that implementation costs are actually positive for a considerable proportion of farms), which can also explain the (partial) non-adoption of such measures in the absence of extra incentives (Moran et al., 2013).

The reasons determining adoption or non-adoption of production technologies apparently also apply to technological GHG emission mitigation options. The remarks outlined in this section should help to understand that profit maximisation is only one aspect that determines a farmer's decision to adopt a specific technology or management practice on the farm. Therefore, there is a need to invest in behavioural economic tools to better understand non-adoption behaviour. All the other determinants discussed in this section also have to somehow be considered in the CAPRI modelling approach for the costs and uptake of technological mitigation options. In the following section, we outline the basics of this approach.

4.3 Methodology of modelling costs and uptake of mitigation technologies

In this section, we outline the general specification of the cost functions in the CAPRI supply module, followed by the specific approach taken for abatement cost curves related to the implementation of the technological emission mitigation options.

General specification of cost functions in the CAPRI supply module

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. The 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.[19] 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).

Specific approach for abatement cost curves

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[20] 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. 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:

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

[19] This applies to the production of a certain commodity (e.g. maize) in a specific NUTS 2 region (e.g. Andalucía).
[20] As mentioned above, this information comes from the GAINS database.

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 previous 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.

Parameter specification when the mitigation technology is already adopted in the base year

To specify the cost parameters that are not depicted in the cost database (i.e. the ones relating to the above-outlined determinants for technology adoption), 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):

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

where

$mshar^0_{a,m,e}$	current mitigation share according to historic data (GAINS database), *m0* in Figure 18.

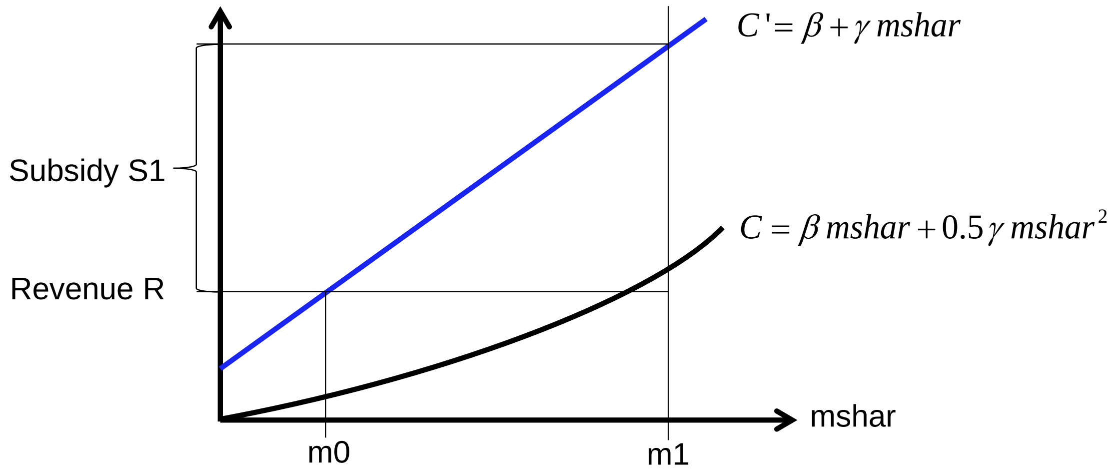
The second condition is an assumption related to responsiveness, namely the specification of a non-linear cost function with smooth behaviour of uptake of the technological mitigation options. For a certain subsidy, *S*, the optimal solution would be the implementation of a mitigation technology up to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

$mshar^{1}_{a,m,e} = mshar^{\max}_{a,m,e}$ (*m1* in Figure 18)

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

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

Figure 18: Representation of mitigation cost curves in CAPRI with positive initial implementation

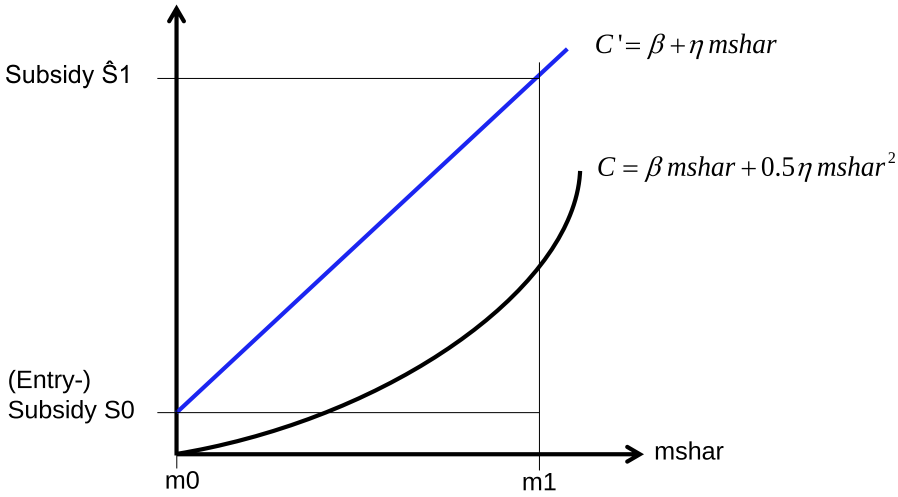


We assume for the time being that the implementation of a mitigation technology would be at its maximum if a relative subsidy ($S^{1}_{a,m,e}$) of 80 % of the accounting costs from GAINS ($\kappa_{a,m,e}$) is paid. The assumption of 80 % explicitly allows for some responsiveness of the farming sector 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.

Parameter specification when the mitigation technology is not adopted in the base year

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 previous section. 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 Figure 19. A numerical example for a better understanding of this approach is given in Annex 1.

Figure 19: Representation of mitigation cost curves in CAPRI with zero initial implementation



Sensitivity of our modelling approach for the uptake of mitigation technologies

It has to be stressed that the empirical evidence for the specification of the threshold values for the relative subsidies assumed in our modelling approach is difficult to come by or is non-existent, especially when considering the nature of future mitigation options. However, even if the presented approach may have a weak empirical basis, the alternative of using only the cost depicted in the GAINS database was considered further away from reality. For instance, this would imply that farmers are homogeneous in a region and would happily switch from one economic or production option to the next if the latter increases regional income by one Euro. Such ‘jumpiness’ in farmers’ behaviour contradicts all anecdotal evidence and also the determinants for technology adoption outlined in the section on the (non-)adoption of technologies by farmers. Moreover, the use of step-wise adoption cost functions (i.e. typically used in technology-rich models) would make scenario analysis in an economic model such as CAPRI very difficult from a computational point of view. In Annex 3, we present a sensitivity analysis regarding the assumed relative subsidy necessary to achieve a 100 % adoption of a technology.

5 Scenario definition

In this chapter, the main assumptions taken in the reference scenario (section 5.1) and GHG mitigation policy scenarios (section 5.2) are presented.

5.1 Reference scenario

CAPRI is a comparative static model that requires a projected equilibrium state of global agricultural markets in the future in order to perform comparative simulation analysis. 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[21] (i.e. a projection of 10 years ahead) 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. 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 for EcAMPA 2 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 for EcAMPA 2, with which GHG mitigation policy scenarios are compared.

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 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).[22] The CAPRI baseline does not anticipate any potential World Trade Organization (WTO) agreement in the future, and no assumptions are made concerning bilateral trade agreements that are currently under negotiation. The policy and market assumptions in the reference scenario are further outlined below.

CAP assumptions

The policy assumptions in CAPRI until 2014 are described in detail in Britz and Witzke (2014). The latest CAP reform, however, implies changes in terms of both the budget and the applicable policy measures. The former Single Payment Scheme (SPS) has been replaced by the Basic Payment Scheme (BPS). The Single Area Payment Scheme (SAPS) remains in place, and a possibility to opt for other related payments has been added according to Council Regulation (EC) No 1307/2013. The interaction between premium entitlements and eligible hectares for the BPS, SAPS and other payments remains explicitly considered. Member States can change their decisions regarding the implementation of certain measures, for example transfer of subsidies between Pillar I and Pillar II until 2020. In the CAPRI baseline, it is assumed that Member States' decisions/notifications will not change after 2015. Naturally, the CAPRI baseline explicitly covers only those direct support measures of the CAP reform 2014–2020 that can be implemented at the national or regional level, such as national ceilings[23] for direct payments, basic payment[24] and voluntary coupled support.[25] Measures that need to be implemented at the farm level (e.g. payment for agricultural practices beneficial for the

[21] 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).
[22] For more information, see: http://ec.europa.eu/agriculture/cap-post-2013/index_en.htm
[23] Regulation (EU) No 1307/2013, Article 6.
[24] Regulation (EU) No 1307/2013, Article 22.
[25] Regulation (EU) No 1307/2013, Article 53.

climate and the environment[26] and voluntary redistributive payments[27]) are only implicitly covered via the underlying market projections from the European Commission (2014b).[28] Decoupled and coupled direct payments in CAPRI are highly disaggregated, in terms of both regional resolution and production structure. In addition to decoupled support in BPS or SAPS, the Voluntary Coupled Support (VCS) scheme is also implemented in CAPRI. The implementation of VCS in CAPRI is in line with the latest CAP reform package, where Member States have more options to provide coupled support. The implementation in CAPRI is based on the latest Member State declarations, with most of the VCS premiums targeting the beef, dairy, sheep's and goat's milk, protein crops, fruit and vegetables, sugar beet, cereal, rice and olive oil sectors. The core policy assumptions of the CAP in the current CAPRI baseline are summarised in Table 3.

Table 3: Core policy assumptions for the reference scenario

PILLAR I		
Instrument	**Base year 2008**	**Baseline 2030**
Direct payments	As defined in 2003 reform and 2008 Health Check; 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 as notified by MS up to 01/08/2014*
Redistributive payment	NA	Not implemented
Young Farmer Scheme	Not implemented	Not implemented
Green Payment	NA	Granted without restriction (only conversion of permanent grassland is restricted)*
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	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
Nitrates Directive		
Instrument	**Base year 2008**	**Baseline**
Requirements for manure storage, application, balanced fertilisation	As reflected in observed application of organic and mineral fertilisers	Additional feed efficiency gains and constrained growth of animal herds in some MS

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

[26] Regulation (EU) No 1307/2013, Article 47.
[27] Regulation (EU) No 1307/2013, Article 42.
[28] Explicit implementation would require the use of the CAPRI farm module, as these policy measures are farm specific. The above policy measures in the CAPRI farm module are, however, not operational at the time of writing this report.

Macroeconomic and market assumptions

The CAPRI baseline integrates a multitude of external information sources for assumptions on macroeconomic and agricultural market developments. Exogenous macroeconomic indicators cover, for example, GDP growth, inflation, exchange rates and population growth, while exogenous market indicators include, for example, assumptions on biofuel production from agricultural feedstocks, use of mineral fertilisers and energy prices. The key macroeconomic and market assumptions for the current CAPRI baseline are summarised in Table 4.

Table 4: Core macroeconomic and market assumptions

Variable	Source	Determines…
Macroeconomics (inflation, GDP growth)	AGLINK, supplemented with GLOBIOM	… some nominal prices, position of demand functions, starting point for future simulations
Demographics	AGLINK, supplemented with GLOBIOM	… position of demand functions, starting point for future simulations
Market balances for EU	European Commission (2014b), supplemented with national/industry sources, sometimes defined by constrained trends	… target values for CAPRI trend estimator (e.g. beef supply)
World markets	European Commission (2014b) supplemented with GLOBIOM plus data consolidation	… international market variables, position of behavioural functions, starting point for simulations
Biofuel policy	European Commission (2014b)/PRIMES	…implicitly harmonized with those in EC MTO through calibration to biofuel supply/use and trade
Yields	European Commission (2014) supplemented with other sources 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

5.2 Mitigation policy scenarios

For this report, four *main* mitigation policy scenarios have been constructed; in addition, four *complementary* mitigation scenarios were included to test alternative policy assumptions (see Table 5). It has to be highlighted that all mitigation policy scenarios are of an exploratory nature and that they in fact do not reflect real 'policy options' considered in the current impact assessment work conducted by the European Commission.

The simulated mitigation policy scenarios rely on the same assumptions as the reference scenario (i.e. assumptions regarding macroeconomic drivers) and domestic and trade policies are also the same as in the reference scenario. The technological mitigation options described in Chapter 4 are available in all scenarios. However, differing from the reference scenario, the main mitigation policy scenarios aim at a compulsory reduction of agricultural GHG emissions in the EU-28 of 20 % in 2030 compared with 2005. The overall 20 % mitigation target is translated into heterogeneous targets per Member State following a cost-effective allocation of mitigation efforts. The allocation of mitigation targets among Member States reflects the results of performing an auxiliary scenario that imposes a carbon price of EUR 50/tonne CO_2 equivalents. Under this auxiliary scenario, the overall mitigation is 9.9 % compared with 2005, with emission efforts heterogeneously distributed among the Member States. For the scenarios within this report, we removed the carbon price but set binding mitigation targets at the Member State level based on the distribution key of mitigation efforts achieved with the auxiliary scenario. To make sure that the 20 % mitigation target is achieved in the main scenarios, a linear shifter was applied to the emissions efforts of all Member States.[29]

In the reference (REF) scenario and HET20 (non-subsidised voluntary adoption of technologies) scenario, no subsidy for the application of mitigation technologies is paid to the farmers, whereas in the SUB scenarios an 80 % subsidy for the voluntary (SUB80V_20) or mandatory (SUB80O_20) application of all mitigation technologies is granted. With the exception of the SUB80V_20TD scenario, all scenarios assume a (standard) 'restricted' potential of technological GHG emission mitigation options based on the literature and expert knowledge (i.e. IIASA, JRC experts and DG-AGRI). The SUB80V_20TD scenario assumes an 'unrestricted' potential (i.e. more rapid technological development than in the other scenarios) of the mitigation technologies, mainly based on the updated GAINS (2015) database.

Regarding the complementary scenarios, HET15 and HET25 have the same assumptions as HET20, but instead of a 20 % mitigation target for EU-28 agriculture they have mitigation targets of 15 % and 25 %, respectively; no subsidies are paid for the application of mitigation technologies. In addition, in scenario SUB80V_15, we apply a mitigation target of 15 % as distributed in HET15, but an 80 % subsidy for the voluntary application of mitigation technologies is paid. Finally, with the scenario SUB80V_noT, we run a scenario without any specific mitigation targets but with an 80 % subsidy for the voluntary application of mitigation technologies. This scenario mimics the situation currently present in the CAP, where targets are not directly imposed on the farming sector, and where mitigation technologies are mainly supported by voluntary decisions by farmers.[30] Table 5 presents an overview on the EcAMPA 2 scenarios.

[29] Regarding the auxiliary scenario with a carbon price, see also Annex 4 on the impact of different carbon prices on the distribution of mitigation efforts.

[30] It has to be noted that the aid intensity under rural development for investments is much lower than 80 %.

Table 5: Scenario overview

Scenario Name	Scenario description
Reference Scenario (REF)	– No specific mitigation target for EU-28 agriculture – No subsidy for the application of mitigation technologies – 'Restricted' potential of the mitigation technologies
Non-subsidised Voluntary Adoption of Technologies (HET20)	– Compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness – No subsidy for the application of mitigation technologies – 'Restricted' potential of the mitigation technologies
Subsidised Voluntary Adoption of Technologies (SUB80V_20)	– Compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness – 80% subsidy for the voluntary application of all mitigation technologies – 'Restricted' potential of the mitigation technologies
Subsidised Mandatory/Voluntary Adoption of Technologies (SUB80O_20)	– Compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness – 80% subsidy for the mandatory application of selected* mitigation technologies – 80% subsidy for the voluntary application of the remaining mitigation technologies – 'Restricted' potential of the mitigation technologies
Subsidised Voluntary Adoption of Technologies (with more rapid technological development) (SUB80V_20TD)	– Compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness – 80% subsidy for the voluntary application of all mitigation technologies – 'Unrestricted' potential of the mitigation technologies (i.e. more rapid technological development)
Complementary scenarios	
HET15, HET25	– As HET20, but with a compulsory 15% and 25% mitigation target for EU-28 agriculture, respectively, allocated to MS according to cost-effectiveness
SUB80V_15	– As SUB80V_20, but with a compulsory 15% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness
Subsidised Voluntary Adoption of Technologies, No Mitigation Target (SUB80V_noT)	– No specific mitigation target for EU-28 agriculture – 80% subsidy for the voluntary application of all mitigation technologies – 'Restricted' potential of the mitigation technologies

* Anaerobic digestion, VRT, increasing legume share in temporary grassland.

Treatment of the technological mitigation options in the scenarios

Table 6 presents the technological mitigation options described in section 4.1 and their treatment in the scenarios. As can be seen, 12 technologies are available for the farmers in all scenarios. However, in the scenario SUB80V_20TD, two additional technologies (nitrate as a feed additive to reduce CH_4 emissions from enteric fermentation, and vaccination against methanogenic bacteria in the rumen) are available. Furthermore, while under the 'restricted potential' assumption, the reduction of emissions owing to fertiliser measures (precision farming, VRT, nitrification inhibitors, fertiliser timing) is constrained, but this restriction is removed under the 'more rapid technological development' assumption (see also the information given in Annex 2). Moreover, SUB80V_TD assumes a greater potential for genetic improvements with regard to the increase in milk yields of dairy cows (see section 4.1).

Table 6: Technological GHG mitigation technologies and their treatment in the scenarios

Mitigation Technology	REF/ HET15/HET20/ HET25	SUB80V_noT SUB80V_15 SUB80V_20	SUB80O_20	SUB80V_20TD
1. Anaerobic digestion: farm scale	A+noS	A+SV	A+SM	A+SV
2. Better timing of fertilization	A+noS	A+SV		A+SV (unrestricted)
3. Nitrification inhibitors	A+noS	A+SV		A+SV (unrestricted)
4. Precision farming	A+noS	A+SV		A+SV (unrestricted)
5. Variable Rate Technology (VRT)	A+noS	A+SV	A+SM	A+SV (unrestricted)
6. Increasing legume share on temporary grassland	A+noS	A+SV	A+SM	A+SV
7. Rice measures	A+noS	A+SV		
8. Fallowing histosols	A+noS	A+SV		
9. Low nitrogen feed	A+noS	A+SV		
10. Feed additives: linseed	A+noS	A+SV		
11. Genetic improvements: increasing milk yields of dairy cows	A+noS	A+SV		A+SV (full potential)
12. Genetic improvements: increasing ruminant feed efficiency	A+noS	A+SV		
13. Feed additives: nitrate	Not available			A+SV
14. Vaccination against methanogenic bacteria in the rumen	Not available			A+SV

Note: A+noS = available for farmers without subsidy; A+SV = subsidised and voluntary for farmers to adopt; A+SM = subsidised and mandatory for farmers to adopt; unrestricted = more rapid technological development of the mitigation technologies.

6 Scenario results

In this chapter, we present results of the reference and mitigation policy scenarios. Results of the main mitigation policy scenarios (i.e. the ones with a 20 % reduction target) are presented in section 6.1 and results of the complementary scenarios are presented in section 6.2. As we are interested in separating the policy effect from the effects without a specific emission reduction policy in place, results of the mitigation policy scenarios are generally presented relative to the reference scenario (i.e. counterfactual analysis).

6.1 Results of the main scenarios

This section presents results of the reference (REF) scenario and the mitigation policy scenarios intending for a 20 % reduction of agricultural GHG emissions, without (HET20 scenario) and with an 80 % subsidy for the implementation of technological mitigation options (SUB80V_20, SUB80O_20 and SUB80V_20TD scenario variants).

6.1.1 Changes in agricultural GHG emissions

The REF scenario projects the development of EU agricultural and associated GHG emissions based on the current market and policy framework (i.e. as depicted in the baseline by 2030). Here we compare emissions in 2030 (REF scenario) to historical emissions in 2005 (EEA inventories). The mitigation policy scenarios show the effect on emissions in 2030 relative to the REF scenario.

GHG emissions in the REF scenario in 2030 are a result of the general policy and market developments and, in some cases, the voluntary application of mitigation technologies. As can be seen in Table 7, if no specific mitigation policy is applied (REF scenario), the EU-28 agricultural GHG emissions are projected to decrease by about 2.3 % by 2030 compared with 2005. However, projection results are rather diverse across Member States. At aggregated EU-N13 level, emissions increase by more than 1 %, whereas emissions in the EU-15 decrease by about 3 %. Over the projection period, 12 Member States are projected to show increases in their agricultural emissions, while the other Member States show emission decreases. The highest increases are projected for Estonia (28.5 %), 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 (−12.5 % each) and the United Kingdom (−10 %).

By design, all four policy scenarios meet a 20 % GHG emission mitigation target for EU-28 agriculture[31] (with about a 0.5 % higher reduction in the three scenarios where subsidies for the application of mitigation technologies are paid). The emission reductions in the policy scenarios directly reflect the mitigation targets imposed per Member State and they are achieved by the reduction of activity levels and the application of mitigation technologies. However, in the scenarios with subsidies for the application of mitigation technologies, Finland shows a substantial increase in emission mitigation beyond its national target in the HET20. Additional mitigation also occurs in some other countries, but, with the exception of the Netherlands, this additional mitigation is usually well below 1 %.[32]

[31] For example, in HET20, the total mitigation compared with 2005 is (−17.8 %) + (−2.3 %) = −20.1 %.

[32] Finland and the Netherlands show further decreases in the subsidy scenarios compared with HET20 owing to the significance of histosol areas in the two countries, which are partly taken out of production if this is subsidised via the mitigation measure ‘fallowing histosols’.

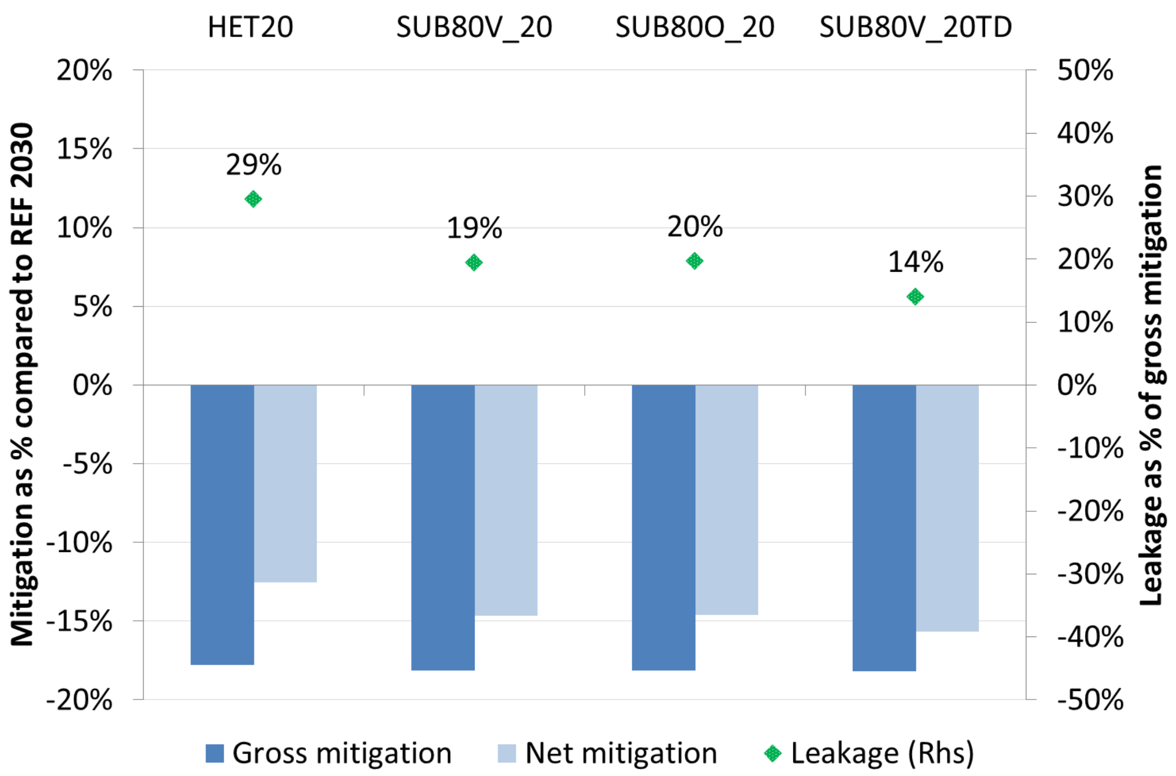
Table 7: Changes in agriculture GHG emissions per EU Member State in 2030

	REF		HET20	SUB80V _20	SUB80O _20	SUB80V _20TD
	1000t CO2eq	%-change 2030 vs 2005	%-change compared to REF			
EU-28	399,514	-2.3	-17.8	-18.2	-18.2	-18.2
Austria	6,907	1.1	-14.4	-14.2	-14.2	-14.2
Belgium-Lux	8,129	-12.5	-17.9	-17.7	-17.7	-17.7
Denmark	11,099	-0.5	-20.6	-20.4	-20.4	-20.4
Finland	7,253	3.9	-27.6	-40.4	-40.4	-40.2
France	69,389	-4.3	-16.7	-17.1	-17.1	-17.2
Germany	60,797	-2.2	-19.7	-20.1	-20.1	-20.0
Greece	6,174	-2.6	-13.9	-13.9	-13.9	-13.9
Ireland	21,934	2.4	-15.2	-15.0	-15.0	-15.0
Italy	25,213	-16.3	-15.0	-14.6	-14.6	-14.6
Netherlands	18,621	-1.4	-16.2	-17.7	-17.7	-18.0
Portugal	6,278	9.3	-18.6	-18.5	-18.5	-18.4
Spain	35,272	11.6	-17.8	-17.9	-17.9	-17.9
Sweden	7,126	-1.3	-15.5	-15.5	-15.5	-15.5
United Kingdom	43,326	-9.8	-16.0	-16.0	-16.0	-16.0
EU-15	327,518	-3.2	-17.3	-17.8	-17.8	-17.8
Bulgaria	3,977	5.0	-15.5	-15.3	-15.3	-16.1
Croatia	2,170	-4.2	-14.0	-13.8	-13.8	-13.8
Cyprus	446	14.2	-15.8	-15.9	-15.9	-15.9
Czech Republic	6,080	-0.1	-19.2	-19.3	-19.3	-19.6
Estonia	1,661	28.5	-26.8	-26.7	-26.7	-26.8
Hungary	6,335	1.9	-20.3	-20.3	-20.3	-21.1
Latvia	2,505	21.7	-15.5	-15.4	-15.4	-15.7
Lithuania	4,488	8.2	-19.6	-19.5	-19.5	-19.8
Malta	62	-25.3	-13.3	-13.1	-13.1	-13.1
Poland	28,928	6.1	-23.8	-23.8	-23.8	-23.6
Romania	12,083	-13.0	-14.2	-14.1	-14.1	-14.6
Slovak Republic	2,052	-4.8	-16.9	-16.8	-16.8	-17.1
Slovenia	1,209	-1.4	-15.9	-15.8	-15.8	-15.7
EU-N13	71,996	1.4	-19.9	-19.8	-19.8	-20.0

As mentioned in the section on methodology (section 3.3), to gain a broader understanding of the net contribution of imposing GHG mitigation obligations on the EU agriculture sector, possible emission leakage has to be considered. Therefore, the mitigation effort in the EU has to be combined with the change in GHG emissions in the rest of the world that may occur because of changes in trade flows associated with decreases in EU agricultural production owing to domestic mitigation obligations.

Emission mitigation and leakage as percentages of gross mitigation are presented in Figure 20. Gross mitigation considers only the mitigation undertaken in the EU-28, whereas net mitigation discounts the increased emissions in the rest of the world. In the scenarios, emission leakage is calculated as the proportion of gross mitigation that is offset by changes in the emissions of the agricultural sector in the rest of the world. The point values in Figure 20 show the percentage of emissions reduced in the EU-28 that are compensated for by an increase in emissions in the rest of the world. This emission increase is due to the additional production that occurs in the rest of the world, either to substitute exports from the EU-28 or to allow additional imports in the EU-28. Scenario results show that the introduction of an emission reduction target only in the EU would indeed lead to an increase in emissions in the rest of the world. However, the amount of emissions leaked varies between the scenarios. In HET20, results show that 29 % of the GHG emissions mitigated in the agriculture sector in the EU are compensated for by emissions in the rest of the world. However, once technologies for mitigation are subsidised (SUB80V and SUB80O) the rate of emission leakage decreases by about 10 percentage points, because more production remains in the EU as farmers mitigate more emissions via the use of technologies instead of reducing production. Moreover, if we assume an 'unrestricted' potential (i.e. more rapid technological development than in the other scenarios) of the mitigation technologies (SUB80V_TD), leakage is further reduced and about 14 % of emissions mitigated in the EU are compensated for by emission increases in the rest of the world.

Figure 20: Emission mitigation and leakage as percentages of gross mitigation



Looking into the geographical distribution of the increased emissions in the rest of the world (Figure 21), it can be seen that most of the emission increases take place in Asia, followed by Middle and South America. This pattern holds for all scenarios except for the one assuming more rapid technological development, where the region that is the second highest contributor to leakage is non-EU Europe (i.e. Commonwealth of Independent States countries). The slight change in geographical distribution between the scenarios can be attributed to the nature of production reductions in the EU-28 under the different scenarios, which leads to different imports that come from different regions. In the context of the analysis on emission leakage, it has to be mentioned that, for this analysis, non-EU countries are not assumed to take explicit measures to reduce GHG emissions in agriculture. However, technology is assumed to continue developing following historical trends in non-EU countries, so that, for example, yield improvements might allow for lower emissions per production unit in the reference scenario compared with the base year.

Regarding the change in emissions in the rest of the world by commodity (Figure 22), the majority of emission leakage is the result of increased production of beef cattle in the rest of the world, which is increased to compensate for production decreases in the EU (to be further discussed in the next section in the context of EU changes in production levels).

Figure 21: Geographical distribution of the increased emissions in the rest of the world

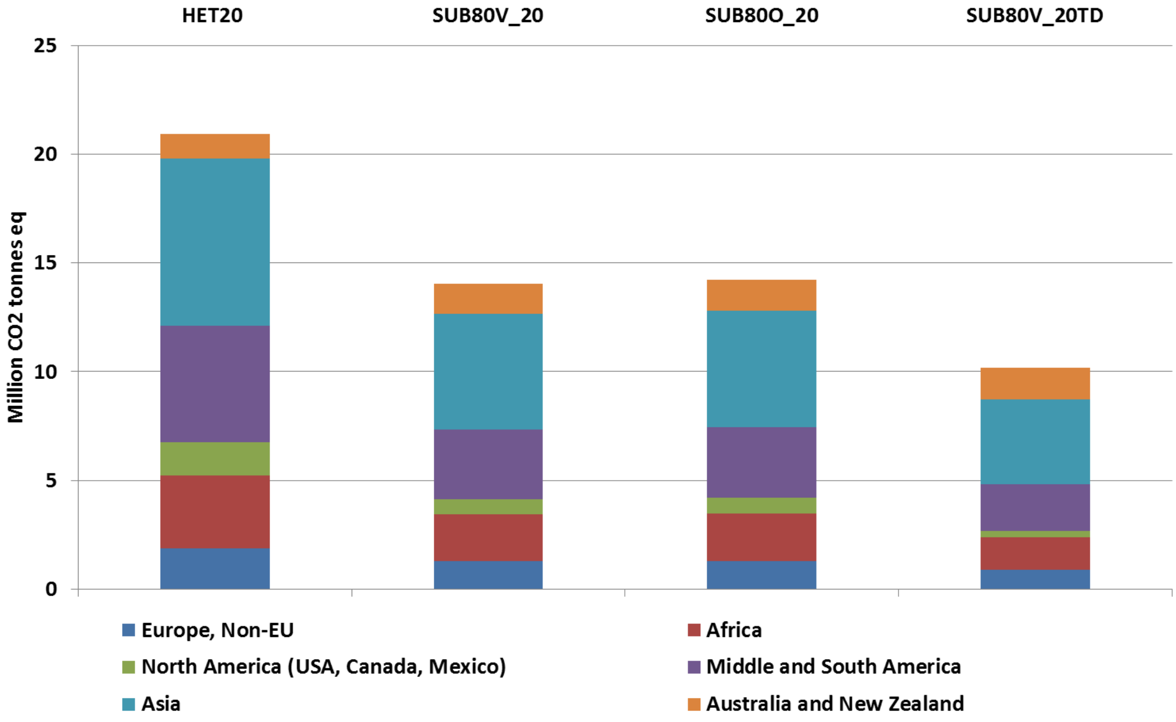
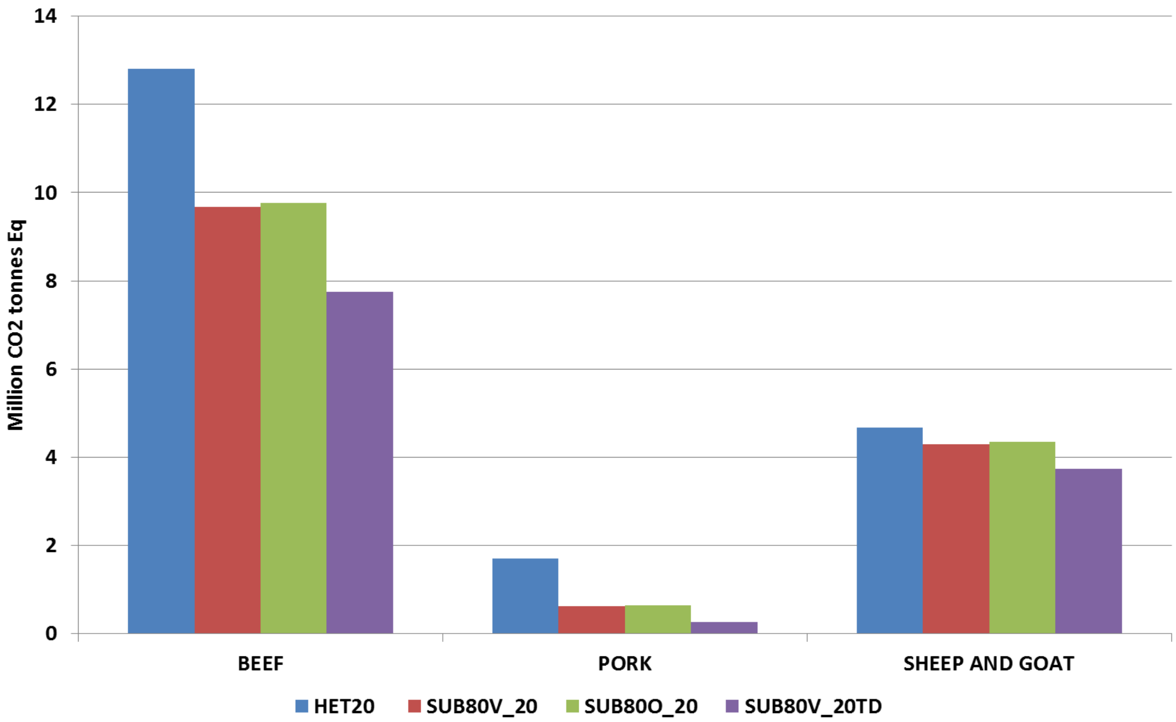


Figure 22: Change in emissions in the rest of the world by commodity



6.1.2 Impact on agricultural production

Table 8 gives an overview of how the effects of the mitigation policies are distributed across activities in the EU-28. Developments of beef, dairy and pig herd sizes and production at the Member State level in each scenario are presented in Table 9 to Table 11, and information on cereal area and production is given in Table 12.

Table 8 shows that, as a general rule, domestic production is most affected in the HET20 scenario. When subsidies are paid out for mitigation technologies, the impact of the 20 % mitigation target on supply is considerably reduced (SUB80V_20 and SUB80O_20), and subsidies, in combination with the assumptions of more rapid technological development (SUB80V_20TD), further smoothen the negative production effects of a mitigation target. However, as can be seen in Table 9 to Table 12, the impacts on agricultural activities between Member States are quite diverse, which is attributable to the following factors: (1) the specific mitigation target for each Member State, (2) the relative strength of the sector and (3) whether subsidies are paid or not for the adoption of mitigation technologies. All policy scenarios show generally higher decreases in the number of hectares or herd sizes than in production, indicating some considerable efficiency gains. However, while these efficiency gains can partly be attributed to the use of technological mitigation options, a greater proportion of the gains in efficiency might be attributed to a different production mix, such that activities with high emission intensities are reduced first, while more productive crop activities and animals are maintained. For instance, within a region, less productive areas and animals might be taken out of production first, while more productive areas and animals will be kept.

In all scenarios, the largest effects on production activities generally take place in the EU livestock sector, with the herd size of beef production activities being most affected. For example, in the HET20 scenario, beef cattle herds decrease by 16 % and beef production by 9 %. This effect could be higher if border protection measures were not in place. In all scenarios, the beef cattle herd decreases more than production. When subsidies are paid for mitigation technologies, the impact on the beef sector is reduced, with beef herd sizes decreasing by about 10 % and production 6 % in SUB80V_20 and SUB80O_20, while in SUB80V_20TD decreases of 6.6 % in herd size and 4 % in production are indicated. Results at the Member State level (Table 10) generally confirm the scenario trends indicated at the aggregated EU-28 level. Relative reductions in beef herd sizes are considerably higher in the EU-N13 than in the EU-15 Member States (e.g. in HET20, −27.5 % in the EU-N13 and −15 % in the EU-15). In the HET20 scenario, for the EU-N13, the highest (relative) decreases in animal numbers and production are projected to take place in Estonia, Croatia, Lithuania, Hungary and the Czech Republic. In the EU-15, Denmark shows the highest decrease in both beef herd size (−40 %) and production (−16 %), followed by Greece (−25 % herd size, −8 % production) and the Netherlands (−24 % herd size, −8 % production). In the scenarios with subsidies, the effect of the mitigation target on beef cattle is particularly reduced in the Netherlands, where herds decrease in SUB80V_20 by 4.5 % compared with the REF scenario.

The dairy sector is generally less affected than the beef sector, with a reduction of the EU dairy herd size between 3.4 % (HET20) and 2.7 % (SUB80V_20TD). While milk production in HET20 decreases by 2 %, the subsidy paid for breeding programmes intended for increasing dairy cow yields leads to almost no change in total EU milk supply (SUB80V_20 and SUB80O_20) or even to an increase of 1 % when more rapid technological development with a higher increase in milk yields is assumed (SUB80V_20TD). In general, results at the Member State level follow the developments indicated at the EU-28 level (Table 10). With the subsidy paid for milk yield breeding, increases in milk supply are on average higher at the EU-N13 than the EU-15 level, which is not really surprising, as owing to lower starting levels there is generally more scope for yield improvements in the EU-N13 Member States than in most of the EU-15. Nonetheless, especially for Ireland, milk supply also increases considerably in the EU-15 with the introduction of mitigation subsidies compared with the REF scenario (between 5.8 % in SUB80V and 6.6 % in SUB80V_TD).

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 (between 39 % in SUB80V_20TD and about 46.5 % in SUB80O), effects on crop production are rather moderate in relative terms in all scenarios, with agricultural area in the EU-28 decreasing between 3 % (HET20) and 1.5 % (SUB80V_20TD). However, in absolute terms, this means a decrease in UAA between 2.8 and 5.7 million ha. For cereals, area and production decrease at almost the same relative levels in the aggregated EU-28, between 4 % in HET20 and 2 % in SUB80V_TD. At the Member State level, in the HET20 scenario, cereal area is most affected in Finland (−10 % in area, −9 % in production), Slovenia (−10 % in area, −8 % in production) and Germany (about −8 % in area and −7 % in production) (Table 12), while for Ireland an increase in area and production of 4 % is projected (the latter resulting from the dominance of grassland in agricultural area in Ireland, which would decline with the beef sector). Again, in the scenarios with subsidies paid for mitigation technologies, the decreasing effect of the mitigation target is generally dampened (i.e. reductions in cereal area and production in the subsidy scenarios are lower than in the HET20 scenario), and might in some countries even lead to an increase in cereal production compared with the REF scenario. In Ireland, production is further augmented in the subsidy scenarios to a production increase of about 8 %. By contrast, Finland and the Netherlands show further decreases in the subsidy scenarios compared with HET20, which is a result of the significance of histosols area in these countries, which are partly taken out of production if this is subsidised under the mitigation measure 'fallowing histosols'.

Regarding changes in the pig meat sector, impacts vary between a reduction of 4 % in HET20 and an increase in production of 0.4 % in SUB80V_20TD at the aggregated EU-28 level. What is notable when looking at Table 11 is that the effects on herd size and production match each other. This is due to a general lower possibility for efficiency gains in the pig sector (i.e. as the pig sector has a lower flexibility and is less complex than the cattle sector, it offers fewer possibilities to reduce production in those parts with above average emission intensities). Moreover, there are no pig-specific mitigation technologies available in the scenario (e.g. there is no breeding programme for feed efficiency for pigs).

Table 8: Changes in area, herd size and supply for the EU-28 for activity aggregates

	REF		HET20		SUB80V _20		SUB80O _20		SUB80V _20TD	
	Hectares or herd size	Supply	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	%-difference to REF							
Utilized agricultural area	180,898	na	-3.1	na	-2.4	na	-2.4	na	-1.5	na
Cereals	57,270	336,323	-4.4	-4.6	-3.1	-3.1	-3.2	-3.1	-1.9	-1.9
Oilseeds	12,040	34,137	-2.5	-2.5	-2.4	-2.4	-2.4	-2.4	-1.5	-1.7
Other arable crops	5,656	na	-1.3	na	-1.3	na	-1.3	na	-1.0	na
Vegetables and Permanent crops	16,846	na	0.1	na	0.1	na	0.1	na	0.1	na
Fodder activities	82,230	42,261	-7.3	-10.8	-6.4	-10.1	-6.5	-10.2	-5.0	-7.9
Set aside and fallow land	6,856	na	46.4	na	46.2	na	46.5	na	38.9	na
Dairy cows	21,517	172,726	-3.4	-2.0	-3.2	0.1	-3.2	0.1	-2.7	1.0
Beef meat activities	17,985	7,822	-16.1	-8.9	-10.2	-6.0	-10.4	-6.1	-6.6	-4.1
Pig fattening	233,781	22,653	-4.0	-4.1	-0.6	-0.5	-0.7	-0.6	0.4	0.4
Pig Breeding	11,897	238,852	-3.9	-4.0	-0.6	-0.6	-0.7	-0.7	0.4	0.4
Milk Ewes and Goat	76,341	4,502	-9.1	-7.1	-7.7	-6.6	-7.9	-6.8	-5.9	-5.2
Sheep and Goat fattening	44,235	754	-8.8	-8.3	-7.0	-6.6	-7.2	-6.7	-5.3	-4.9
Laying hens	545	8,244	-2.0	-1.7	-1.3	-1.1	-1.3	-1.1	-0.8	-0.6
Poultry fattening	6,882	14,531	-1.2	-1.3	0.3	0.1	0.3	0.1	0.8	0.6

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

Table 9: Changes in beef herd size and production per EU Member State

	REF		HET20		SUB80V _20		SUB80O _20		SUB80V _20TD	
	Herd size	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.
	1000 hds	1000 t	%-difference to REF							
EU-28	17,985	7,822	-16.1	-8.9	-10.2	-6.0	-10.4	-6.1	-6.6	-4.1
Austria	419	193	-16.6	-10.7	-9.1	-6.9	-9.1	-6.9	-3.5	-3.5
Belgium-Lux	396	230	-10.7	-7.8	-5.2	-5.2	-5.7	-5.5	-2.3	-3.6
Denmark	112	124	-39.9	-16.1	-22.6	-9.7	-22.7	-9.8	-12.5	-5.9
Finland	136	69	-12.6	-6.0	-2.9	-0.1	-2.8	-0.1	-3.3	-1.1
France	5,029	1,751	-14.4	-10.0	-9.2	-7.3	-9.2	-7.3	-5.5	-4.9
Germany	1,231	996	-14.9	-8.5	-6.3	-4.8	-6.3	-4.8	-1.7	-2.7
Greece	217	51	-25.0	-8.1	-21.8	-7.1	-21.8	-7.2	-18.6	-6.1
Ireland	1,977	616	-13.5	-7.5	-8.8	-4.7	-8.8	-4.7	-5.7	-3.1
Italy	898	594	-6.6	-4.9	-1.5	-1.5	-1.5	-1.5	0.4	-0.2
Netherlands	121	413	-23.7	-8.4	-4.5	-3.3	-4.4	-3.3	-1.6	-2.3
Portugal	592	132	-14.3	-9.9	-9.3	-7.7	-9.3	-7.7	-7.1	-5.7
Spain	2,097	687	-18.5	-6.1	-15.9	-6.1	-16.9	-6.5	-13.6	-5.4
Sweden	332	132	-15.3	-9.7	-9.0	-6.7	-9.0	-6.7	-6.5	-5.4
UK	2,780	890	-15.5	-8.1	-9.6	-5.7	-9.6	-5.7	-6.7	-4.5
EU-15	16,336	6,879	-15.0	-8.4	-9.5	-5.5	-9.6	-5.6	-6.3	-3.8
Bulgaria	44	24	-31.5	-5.7	-22.0	-5.7	-22.0	-5.7	-7.3	-2.7
Croatia	65	45	-47.4	-14.3	-33.7	-10.0	-33.7	-10.0	-19.0	-5.3
Cyprus	4	5	-13.9	-7.4	-8.3	-5.0	-8.3	-5.2	-8.3	-4.6
Czech Republic	317	82	-35.3	-15.5	-22.7	-11.4	-22.7	-11.4	-14.7	-8.0
Estonia	20	14	-49.0	-12.6	-27.5	-8.4	-27.5	-8.4	-19.0	-6.7
Hungary	124	50	-34.5	-13.4	-24.9	-10.3	-24.9	-10.3	-7.9	-3.4
Latvia	27	32	-28.0	-13.1	-17.0	-9.0	-17.0	-9.0	-11.1	-6.8
Lithuania	68	46	-36.6	-14.6	-24.1	-10.6	-24.1	-10.6	-15.3	-7.3
Malta	1	1	-15.4	-12.4	-15.4	-12.4	-15.4	-12.4	-15.4	-10.3
Poland	712	466	-22.8	-14.0	-14.5	-10.4	-14.5	-10.3	-10.8	-8.3
Romania	79	106	-23.4	-11.8	-19.9	-10.9	-19.9	-10.9	-9.6	-5.7
Slovak Republic	24	18	-20.8	-7.4	-16.9	-6.9	-16.9	-6.9	-11.4	-4.8
Slovenia	164	53	-15.2	-5.5	-3.5	-1.1	-3.4	-1.1	3.5	1.6
EU-N13	1,648	943	-27.5	-13.0	-17.6	-9.7	-17.6	-9.7	-10.4	-6.7

Note: Total supply of beef includes beef from suckler cows, heifers, bulls, dairy cows and calves (carcass weight).

Table 10: Changes in dairy herd size and milk production per EU Member State

	REF		HET20		SUB80V _20		SUB80O _20		SUB80V _20TD	
	Herd size	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.
	1000 hds	1000 t	%-difference to REF							
EU-28	21,517	172,726	-3.4	-2.0	-3.2	0.1	-3.2	0.1	-2.7	1.0
Austria	497	3,949	-3.1	-2.2	-3.0	0.1	-3.0	0.1	-2.3	1.5
Belgium-Lux	565	4,431	-2.6	-1.3	-2.4	1.0	-2.5	0.9	-2.3	1.6
Denmark	598	5,971	-4.4	-4.1	-2.6	-2.3	-2.6	-2.3	-1.8	-1.4
Finland	226	2,361	-2.1	-2.0	-1.5	-1.3	-1.5	-1.3	-1.8	-1.5
France	3,619	28,269	-2.6	-1.7	-3.0	0.1	-3.0	0.1	-2.6	1.0
Germany	4,020	36,161	-2.7	-2.0	-2.5	-0.9	-2.5	-0.9	-2.0	-0.1
Greece	81	593	-0.9	2.1	-1.2	3.6	-1.2	3.6	-1.4	4.0
Ireland	1,317	7,530	-3.3	0.4	-3.9	5.8	-3.9	5.8	-3.6	6.6
Italy	1,650	12,398	-2.0	-0.6	-1.4	2.5	-1.4	2.5	-1.2	3.7
Netherlands	1,527	14,719	-3.2	-3.0	-1.0	-0.2	-1.0	-0.2	-0.9	0.2
Portugal	201	2,063	-3.7	-2.5	-4.0	-2.0	-4.0	-2.0	-2.9	-0.6
Spain	690	6,453	-1.1	-0.6	-1.4	0.0	-1.4	0.0	-1.2	0.6
Sweden	298	3,022	-2.5	-2.2	-2.0	-1.3	-2.0	-1.3	-1.6	-0.9
UK	1,863	17,027	-2.9	-2.3	-2.5	-0.8	-2.5	-0.8	-2.3	-0.2
EU-15	17,149	144,947	-2.7	-1.8	-2.4	0.1	-2.4	0.1	-2.1	0.9
Bulgaria	229	1,036	-5.8	-4.1	-5.7	3.5	-5.7	3.5	-3.1	8.2
Croatia	153	755	-3.2	-0.6	-4.8	0.1	-4.8	0.1	-4.2	0.6
Cyprus	23	209	-0.9	-0.1	-1.3	0.3	-1.3	0.3	-2.2	0.0
Czech Republic	249	2,379	-2.6	-2.1	-3.1	-1.8	-3.1	-1.8	-2.9	-1.2
Estonia	104	951	-2.2	-1.6	-2.4	-0.8	-2.4	-0.8	-2.8	-0.9
Hungary	174	1,508	-5.7	-5.0	-5.5	-3.3	-5.5	-3.3	-2.9	-0.1
Latvia	179	1,109	-3.0	1.1	-4.2	2.6	-4.2	2.6	-4.2	2.2
Lithuania	317	2,028	-5.2	-2.7	-5.1	-0.4	-5.1	-0.4	-4.6	0.8
Malta	5	41	0.0	0.2	0.0	1.7	0.0	1.7	0.0	2.2
Poland	2,054	12,831	-7.1	-3.3	-6.6	0.3	-6.6	0.3	-6.1	2.1
Romania	697	3,530	-7.9	-0.8	-8.4	3.9	-8.4	3.9	-4.9	4.1
Slovak Republic	93	753	-5.7	-4.0	-5.4	-2.0	-5.4	-2.0	-4.1	-0.3
Slovenia	91	648	-1.3	0.9	-2.2	3.9	-2.2	3.9	-2.2	4.2
EU-N13	4,368	27,780	-6.1	-2.5	-6.1	0.5	-6.1	0.5	-5.0	1.9

Table 11: Changes in pig numbers and pork production per EU Member State

	REF		HET20		SUB80V _20		SUB80O _20		SUB80V _20TD	
	Herd size	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.
	1000 hds	1000 t	%-difference to REF							
EU-28	245,679	23,300	-4.0	-4.1	-0.6	-0.5	-0.7	-0.6	0.4	0.4
Austria	3,706	418	-6.6	-6.6	-4.7	-4.7	-4.7	-4.7	-3.0	-3.0
Belgium-Lux	7,685	860	-5.2	-5.2	-1.1	-1.0	-1.3	-1.2	-0.1	0.0
Denmark	28,168	2,243	-5.0	-5.0	-1.7	-1.7	-1.7	-1.7	-0.2	-0.2
Finland	2,295	213	2.3	2.4	8.2	8.2	8.3	8.2	7.6	7.6
France	23,451	2,167	-7.2	-7.2	-0.7	-0.7	-0.6	-0.6	2.3	2.3
Germany	47,522	5,303	-6.4	-6.4	-1.6	-1.6	-1.5	-1.5	-0.3	-0.3
Greece	1,821	93	-0.2	0.1	2.5	2.5	2.5	2.5	2.5	2.4
Ireland	3,635	266	0.5	0.5	6.3	6.3	6.3	6.3	6.2	6.2
Italy	14,208	1,904	-1.1	-1.1	5.6	5.6	5.7	5.7	6.0	6.0
Netherlands	18,520	1,418	-4.1	-4.1	1.1	1.1	0.8	0.9	1.8	1.8
Portugal	3,820	284	-0.9	-0.9	0.4	0.4	0.5	0.5	0.2	0.2
Spain	47,196	4,088	-1.8	-1.8	-0.6	-0.6	-1.0	-1.0	-0.6	-0.6
Sweden	2,014	193	-0.5	-0.5	1.9	1.9	1.8	1.8	2.5	2.5
UK	8,673	645	-1.1	-1.1	-1.5	-1.5	-1.4	-1.4	-1.3	-1.3
EU-15	212,713	20,093	-4.1	-4.2	-0.2	-0.2	-0.3	-0.2	0.7	0.8
Bulgaria	209	12	0.9	0.8	1.1	1.0	1.1	1.0	2.7	2.7
Croatia	2,882	187	0.1	0.1	-0.7	-0.7	-0.6	-0.6	0.6	0.6
Cyprus	796	62	-4.3	-4.3	0.2	0.2	0.1	0.1	0.7	0.7
Czech Republic	810	70	1.1	1.1	4.4	4.4	4.5	4.5	4.3	4.3
Estonia	483	51	1.0	0.9	3.0	3.0	3.0	3.0	2.7	2.8
Hungary	3,048	288	-4.0	-3.9	-2.7	-2.7	-2.7	-2.7	1.0	1.0
Latvia	352	38	-0.9	-0.9	0.5	0.4	0.5	0.4	0.9	0.8
Lithuania	445	41	-0.6	-0.6	0.3	0.3	0.4	0.4	0.8	0.8
Malta	78	6	-0.9	-0.8	9.3	9.1	9.5	9.2	11.3	11.0
Poland	19,370	1,964	-4.9	-4.9	-4.3	-4.3	-4.3	-4.3	-3.7	-3.8
Romania	3,934	427	-1.3	-1.3	-1.9	-1.9	-1.8	-1.8	-0.3	-0.3
Slovak Republic	464	52	-2.5	-2.3	0.1	0.3	0.1	0.3	2.3	2.5
Slovenia	94	9	2.0	2.0	3.3	3.2	3.3	3.3	3.9	3.7
EU-N13	32,966	3,207	-3.5	-3.6	-2.9	-3.0	-2.8	-3.0	-1.8	-2.0

Table 12: Changes in cereal area and production per EU Member State

	REF		HET20		SUB80V _20		SUB80O _20		SUB80V _20TD	
	Area	Prod.	Area	Prod.	Area	Prod.	Area	Area	Area	Area
	1000 ha	1000 t	%-difference to REF							
EU-28	57,271	336,323	-4.4	-4.6	-3.1	-3.1	-3.2	-3.1	-1.9	-1.9
Austria	787	4,999	-1.1	-1.7	-0.1	-0.3	-0.1	-0.3	0.6	0.7
Belgium-Lux	388	3,822	-3.6	-3.6	0.5	0.6	0.1	0.3	0.6	0.6
Denmark	1,381	9,909	0.8	0.4	3.8	3.4	3.8	3.5	3.1	2.7
Finland	1,149	4,964	-9.6	-8.7	-14.5	-13.4	-14.5	-13.4	-13.2	-12.4
France	9,595	73,941	-3.2	-3.0	-1.8	-1.4	-1.8	-1.4	-1.0	-0.8
Germany	6,515	51,645	-8.0	-7.4	-6.8	-6.0	-6.8	-6.0	-4.4	-3.9
Greece	805	4,251	-3.9	-5.2	-2.9	-4.1	-2.9	-4.1	-2.5	-3.8
Ireland	203	1,993	3.9	3.9	7.9	8.1	7.9	8.1	7.9	8.0
Italy	3,273	20,292	-3.8	-3.5	-1.4	-0.8	-1.4	-0.8	-0.3	0.1
Netherlands	207	1,946	-0.8	0.7	-10.8	-8.0	-10.3	-7.3	-10.7	-8.1
Portugal	211	1,156	-6.0	-5.6	-3.6	-3.3	-3.6	-3.3	-2.7	-2.6
Spain	6,115	23,056	-3.1	-5.0	-1.6	-2.8	-2.0	-3.6	-1.4	-2.8
Sweden	854	4,762	-4.7	-4.1	-2.6	-2.1	-2.4	-1.9	-1.8	-1.6
UK	3,050	22,224	-0.4	-0.2	-0.2	0.1	-0.2	0.1	-0.1	0.1
EU-15	34,533	228,960	-3.9	-3.9	-2.7	-2.4	-2.8	-2.5	-1.8	-1.6
Bulgaria	1,919	8,913	-7.1	-7.6	-5.5	-6.0	-5.5	-6.0	-0.7	-0.9
Croatia	542	3,869	-4.0	-4.0	-2.5	-2.4	-2.5	-2.4	-0.7	-0.6
Cyprus	30	65	-3.4	-3.1	-2.4	-2.2	-2.7	-2.3	-2.4	-2.2
Czech Republic	1,674	9,655	-4.8	-6.6	-3.5	-4.7	-3.5	-4.7	-2.1	-3.1
Estonia	324	1,393	-5.1	-5.0	-2.3	-2.2	-2.3	-2.2	-1.4	-1.4
Hungary	2,846	17,303	-3.9	-3.9	-3.2	-3.2	-3.2	-3.2	-1.1	-0.9
Latvia	584	2,201	-1.6	-2.4	-0.6	-1.2	-0.6	-1.2	1.2	0.8
Lithuania	1,059	5,412	-3.5	-6.1	-0.9	-3.0	-0.9	-3.0	0.9	-0.7
Malta	4	20	-5.0	-2.7	-5.0	-2.8	-5.0	-2.8	-2.5	-3.0
Poland	7,791	34,572	-6.1	-8.2	-4.4	-5.9	-4.4	-5.9	-3.6	-5.0
Romania	5,140	19,553	-4.7	-4.6	-4.1	-4.0	-4.1	-3.9	-1.6	-1.7
Slovak Republic	720	3,635	-3.3	-3.4	-2.3	-2.4	-2.3	-2.4	-1.1	-1.1
Slovenia	106	771	-9.6	-8.3	-9.1	-7.6	-9.1	-7.6	-9.0	-7.5
EU-N13	22,738	107,363	-5.1	-6.1	-3.8	-4.5	-3.8	-4.5	-2.0	-2.5

6.1.3 Impact on EU producer and consumer prices

Impacts on producer prices (Table 13) are directly related to how binding the emission mitigation target is in the different scenarios. For instance, in the HET20 scenario, producer prices increase much more than in the SUB80 scenarios, as there are no subsidies that support switching the source of emission savings from production declines towards lower emission technologies. Moreover, producer prices are more affected for those commodities that are more isolated from world markets (i.e. by means of import tariffs or tariff rate quotas). Last but not least, supply and demand elasticities in EU and non-EU regions play an important role as well.

In the HET20 scenario, average EU producer prices range from increases of 1 % for vegetables and permanent crops to 26 % for beef. The large increase in beef prices is linked to the restrictive border measures the EU has in place (i.e. tariff rate quota), which do not allow for a large increase in imports. In general, crop prices are less affected by the emission mitigation target than animal product prices. In the SUB80_20 scenarios, price increases are lower. It is interesting to see that the effect of the subsidies is much larger for animal products, especially for meat prices, where the price increase is significantly lower than in HET20. In the SUB80V_20TD scenario, price changes become negative for dairy products. This is related to the induced production increases shown in the previous section, as especially the breeding for higher milk yields of dairy cows leads to efficiency gains in the dairy sector and results in an increase in total EU milk production.

Since price mark-ups do not change, consumer prices follow pretty much the developments of producer prices, with beef experiencing the largest price variations (Table 14).

Table 13: Change in EU producer prices

	REF	HET20	SUB80V_20	SUB80O_20	SUB80V_20TD
	EUR/t	%-difference to REF			
Cereals	195	1.8	1.7	1.7	0.9
Oilseeds	401	2.2	0.5	0.5	-1.0
Other arable field crops	92	3.0	2.2	2.3	1.4
Vegetables and Permanent crops	853	1.0	1.1	1.1	1.0
Beef	4,363	25.9	16.4	16.6	10.7
Pork meat	1,849	8.8	2.8	2.9	0.9
Sheep and goat meat	6,614	11.4	8.5	8.6	6.0
Poultry meat	1,885	4.0	1.6	1.7	0.7
Cow and buffalo milk	429	12.3	1.8	1.9	-3.1
Sheep and goat milk	962	9.0	3.4	3.4	0.0
Eggs	1,534	4.0	2.5	2.6	1.5

Table 14: Change in EU consumer prices

	REF	HET20	SUB80V_20	SUB80O_20	SUB80V_20TD
	EUR/t	%-difference to REF			
Cereals	3,281	0.1	0.1	0.1	0.1
Oilseeds	3,162	0.2	0.1	0.1	-0.1
Other arable field crops	1,279	0.2	0.2	0.2	0.2
Vegetables and Permanent crops	2,355	0.1	0.1	0.1	0.1
Beef	9,368	12.1	7.7	7.8	5.0
Pork meat	6,417	2.6	0.8	0.9	0.3
Sheep and goat meat	11,179	5.5	4.1	4.2	3.1
Poultry meat	4,322	1.7	0.7	0.8	0.3
Eggs	4,636	1.3	0.8	0.8	0.5
Butter	4,507	7.1	1.3	1.3	-1.4
Cheese	6,477	3.8	0.6	0.6	-0.9

6.1.4 Impact on EU imports, exports and net trade position

Following the production and price developments, we observe a worsening of the net trade position in the EU in all scenarios, with the exception of dairy products in the SUB80V_20TD scenario (Table 15). The largest percentage change in imports can be observed for meats, but with trade representing a very small proportion of domestic production.

Lower imports of oil cakes are related to the fact that beef production decreases. The effect is considerably larger in the SUB80 scenarios, where domestic production is actually less affected through the introduction of mitigation subsidies. The adoption of several mitigation technologies leads to efficiency gains in the beef sector in the mitigation scenarios (e.g. the breeding programmes aiming to increase feed efficiency), which further decreases the domestic demand for oil cakes.

The trade balance for dairy products is improved in the SUB80V_20TD scenario, with lower imports than in the REF scenario. This is mainly linked to the introduction of additional mitigation technologies (and the associated subsidies) in this scenario.

Table 15: Changes in EU imports, exports and net trade position for aggregate activities

	REF			HET20			SUB80V_20			SUB80O_20			SUB80V_20TD		
	Imports	Exports	Net trade	Imports	Exports	Net trade	Imports	Exports	Net trade	Imports	Exports	Net trade	Imports	Exports	Net trade
	1000 t			%-diff to REF		1000 t	%-diff to REF		1000 t	%-diff to REF		1000 t	%-diff to REF		1000 t
Cereals	6,430	53,921	47,491	2.8	-4.0	45,145	5.1	-4.4	44,764	5.2	-4.5	44,734	3.1	-2.5	45,921
Oilseeds	17,795	5,268	-12,528	0.2	-5.5	-12,852	-1.5	-2.9	-12,419	-1.5	-2.9	-12,420	-2.2	0.0	-12,141
Other arable field crops	1,759	3,149	1,390	-3.1	-1.5	1,396	-8.2	-1.3	1,494	-8.2	-1.3	1,494	-9.9	-0.3	1,556
Vegetables and Permanent crops	25,368	6,399	-18,969	1.3	-1.0	-19,356	1.3	-1.3	-19,390	1.3	-1.3	-19,393	1.1	-1.3	-19,331
Oils	12,225	1,695	-10,530	-0.3	-0.6	-10,506	-1.5	-0.3	-10,357	-1.5	-0.3	-10,357	-1.8	0.0	-10,305
Oil cakes	23,859	5,102	-18,757	-12.8	8.9	-15,240	-27.0	19.5	-11,320	-27.1	19.5	-11,287	-29.6	21.7	-10,598
Beef	201	358	157	28.5	-65.3	-134	22.5	-46.5	-55	22.6	-46.9	-57	17.4	-35.3	-4
Pork	298	2,153	1,855	51.3	-38.0	883	15.0	-13.6	1,516	15.6	-14.2	1,503	5.2	-5.1	1,730
Sheep and goat meat	372	51	-321	17.6	-52.3	-413	13.3	-44.2	-393	13.5	-44.7	-394	9.6	-36.8	-375
Poultry meat	351	1,690	1,340	24.7	-18.3	943	9.9	-9.4	1,146	10.1	-9.5	1,143	3.7	-5.2	1,239
Dairy products	149	3,843	3,694	11.6	-8.4	3,352	1.0	-1.5	3,636	1.0	-1.5	3,635	-2.9	2.3	3,785

Note: Net trade = exports – imports.

6.1.5 Adoption of technological mitigation options and associated subsidies

The GHG mitigation efforts reported are the result of two main drivers: changes in agricultural production and application of GHG mitigation technologies. A look at the level of GHG mitigation achieved by the application of technological mitigation options reveals the importance of these options in meeting the overall mitigation target. It also shows the additional mitigation efforts that can be realised when subsidising the mitigation technologies, allowing the decrease of GHG emissions with a lesser impact on EU agricultural production levels (Table 16). It has to be highlighted that the presented contributions of the mitigation technologies do not cover the mitigation achieved via the measures related to genetic improvements ('increasing milk yields of dairy cows' and 'increasing ruminant feed efficiency'), as due to the complexity of these measures it is not possible to disentangle their mitigation effects from the related production effects (see Box 2).

Table 16: Proportion of emission reduction achieved via the mitigation technologies and via changes in production levels and production shifts

	HET20	SUB80V _20	SUB80O _20	SUB80V _20TD
	Share in total GHG emission reduction			
Mitigation technologies*	56%	68%	68%	77%
Change in production**	44%	32%	32%	23%

* Does not include the mitigation effects from the measures related to genetic improvements, as it is not possible to disentangle the effects of the breeding programmes on total agricultural emissions from their related production effects (see Box 2).
** This covers the proportion of emission reduction that cannot be directly attributed to technological mitigation options (i.e. mitigation through changes in production levels and production mix, and also the mitigation effects from the measures related to genetic improvements).

Box 2: Why is the contribution of individual breeding measures to the total mitigation per scenario not specifically identified?

The contribution of individual breeding measures to the total mitigation per scenario cannot be identified. Owing to their additional complexity, the current version of the model cannot disentangle the effects of the breeding programmes on the total agricultural emissions from their related production effects. For example, the breeding programme aiming to increase milk yields leads to decreasing emissions per litre of milk produced, but at the same time to an increase in the emissions per cow (i.e. a cow that produces more milk needs to eat more and hence also emits more). If the efficiency gains in dairy production would simply go along with declining prices, income from milk production would decline and, subsequently, dairy herds would decline, leading to net reductions in EU emissions (e.g. the same amount of milk as in the REF scenario would be produced with fewer cows than in the policy scenario). However, the breeding programme in our scenarios is so successful in increasing milk yields across regions that it leads to efficiency gains in milk production that are strong enough to counteract the decreasing prices and even lead to an increase in total milk production. What we can see in the results of the mitigation scenarios is that total emissions in the dairy sector indeed decrease. However, it is not possible to disentangle the production effect of the breeding programme from the production effect induced by the mitigation target and the total price decrease. An additional complication comes from the effects of increasing milk yields on feeding requirements (which has an effect of emissions per cow). Again, it is not possible to disentangle the effect of the breeding programme on feed requirements from the general change in feeding induced by the market effects as a result of the mitigation target, price developments and reduction in dairy herds.

Table 17 summarises the uptake of the technological mitigation options by farmers in the different scenarios compared with the technical maximum as reported by the GAINS database or the alternative source mentioned in Chapter 4. In the REF scenario, the technologies are available but are not widely adopted by farmers, as, with the exception of anaerobic digesters, adoption would not be profitable for farmers and there is no GHG mitigation target. When we impose a mitigation target without subsidies (HET20), farmers start adopting technologies that reduce activities' profits but still allow these to remain positive. Farmers mainly implement anaerobic digesters, nitrification inhibiters and additional practices in rice cultivation (all three technologies are applied to almost 100 % of the maximum possible level (HET20)), as well as genetic improvements regarding the increase in ruminant feed efficiency (72 % application) and abandoning histosols (69 % of the maximum histosols area in each NUTS 2 region). Other measures that are more widely implemented once a mitigation target is set include precision farming (24 %, with the maximum possible application level being 58 %), linseed as a feed additive (around 13 %, with the maximum possible level being 29 %) and genetic improvements regarding the increase in dairy cow milk yields (about 15 %, with the maximum possible level being 100 %).[33]

Once we introduce subsidies for the technological mitigation measures in the scenarios with a 20 % mitigation target (SUB80V_20 and SUB80O_20), their adoption rate increases, as the costs are reduced and thus profitability is higher. This is particularly important for the options 'increasing legume share on temporary grassland', 'low nitrogen feed' and 'breeding for higher milk yields'. Overall, 80 % of the farmers voluntarily adopt the option of increased legume share and 36 % (of a maximum 56 %) use low nitrogen feed, whereas almost two-thirds of farmers voluntarily adopt breeding for higher milk yields when the measures are subsidised. Regarding increases in the legume share it has to be noted that the table indicates that this mitigation option is voluntarily applied by about 80 % if its uptake is subsidised. However, in some regions, especially in Greece, Austria and Italy, there is no need for subsidies, as the share of legumes on temporary grassland already meets or exceeds 20 % of the total agricultural area (which is why the measure actually achieves an uptake of only about 80 % in the SUB80V instead of 100 %).

A first finding of the scenario with mandatory technologies (SUB80O_20) is that anaerobic digestion does not need to be made mandatory, as it is already adopted by 100 % of the potential farmers when subsidies are offered for a voluntary implementation. This also holds true for the increase in the legume share on temporary grassland. Regarding the adoption of VRT, it has to be stressed that its adoption does not reach the 9 % maximum level that would be envisaged in the SUB80O_20 scenario. The reason for this is that the measure is obligatory only for those farms fulfilling the farm size criterion (i.e. VRT is obligatory only for farms of more than 100 ha, whereas farms of fewer than 100 ha are not obliged to adopt VRT in the scenario). However, the 'maximum possible level' (9 %) also includes the small farms (because they are allowed to implement the measure voluntarily). The maximum level is not 100 % owing to the fertiliser restriction. Making the three technologies compulsory has only minor knock-on effects on the adoption rates of the other fertiliser-related mitigation options, whereas the uptake of all other mitigation technologies remains the same as in the SUB80V_20 scenario.

Under the assumption of more rapid technological development (SUB80V_20TD), the two additional technologies that are assumed to be available to farmers (nitrate as a feed additive and vaccination against methanogenic bacteria) are widely adopted. This is more obvious for the vaccination measure, which is adopted for almost 75 % of the dairy, non-dairy and sheep herds. Assuming more rapid technological development affects other

[33] Whenever the shares of implementation are reported, they refer to the actual proportion of the total area or number of animals. However, as implementation cannot be achieved at 100 % for all technologies, the maximum possible share are also reported in Table 17

measures, and the fact that new feed additives and vaccines are available for cattle means that other technologies related to animal emissions are applied less often. Furthermore, lifting the restriction on the reduction potential (see Chapter 4) of VRT and precision farming also leads to an increase of their application in the SUB80V_20TD scenario at the expense of nitrification inhibitors.

Table 17: Implementation and maximum possible shares of technologies at the EU level by scenario (% of agricultural area or herd sizes)

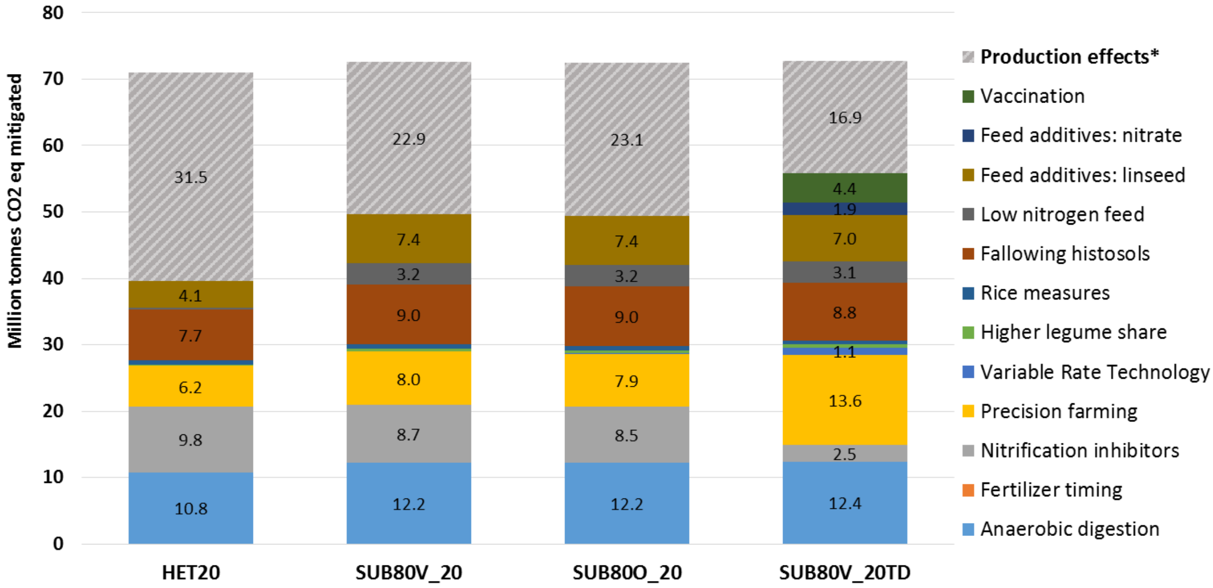
Technology	Implementation share				Maximum possible share			
	HET20	SUB80V_20	SUB80O_20	SUB80V_20TD	HET20	SUB80V_20	SUB80O_20	SUB80V_20TD
Anaerobic digestion	30%	33%	33%	33%	33%	33%	33%	33%
Better fertilization timing	0%	0%	0%	0%	7%	7%	7%	100%
Nitrification inhibitors	57%	51%	50%	14%	60%	60%	60%	60%
Precision farming	24%	33%	32%	60%	58%	58%	58%	100%
Variable Rate Technology	0%	1%	3%	26%	9%	9%	9%	100%
Higher legume share*	19%	78%	80%	78%	100%	100%	100%	100%
Rice measures	98%	96%	96%	87%	100%	100%	100%	100%
Fallowing histosols	69%	82%	82%	80%	100%	100%	100%	100%
Low nitrogen feed	1%	36%	36%	35%	56%	56%	56%	56%
Feed additives: linseed	13%	23%	23%	22%	29%	29%	29%	28%
Increasing milk yields of dairy cows	15%	60%	60%	50%	100%	100%	100%	100%
Increasing ruminant feed efficiency	72%	79%	80%	71%	100%	100%	100%	100%
Feed additives: nitrate	na	na	na	11%	na	na	na	44%
Vaccination (methanogenic bacteria in the rumen)	na	na	na	73%	na	na	na	100%

Note: na = technology not available in the scenario. If an implementation level of 0 % is indicated, it is below 0.5 % at the aggregated EU-28 level.
* The results reported for the measure 'higher legume share' include only those areas where the policy measure leads to an increase of the proportion of legumes on grasslands but does not take into account the areas where, in the baseline, the proportion of legumes on grassland is already above 20 %.

Figure 23 presents a closer look at the absolute contribution and Figure 24 at the relative contribution of each technological mitigation option to the total mitigation in the scenarios. From these figures, it can be seen that, in the scenarios assuming standard technological development, the technology with the highest contribution to emission reduction is anaerobic digestion, followed by nitrification inhibitors, fallowing histosols, precision farming and linseed as a feed additive. In the scenarios with subsidies, nitrate as a feed additive contributes more than 3 million tonnes of CO_2 equivalents, whereas the contribution of other technologies to total mitigation is below 1 million tonnes of CO_2 equivalents. As seen in Table 17, the uptake of certain technologies increases when subsidies are paid for the mitigation technologies, which naturally also increases their contribution to total mitigation compared with the HET20 scenario. In terms of absolute additional mitigation achieved via technologies, this is especially relevant for linseed as a feed additive, low nitrogen feed, anaerobic digestion, fallowing histosols and precision farming (the final one at the expense of the application of nitrification inhibitors).

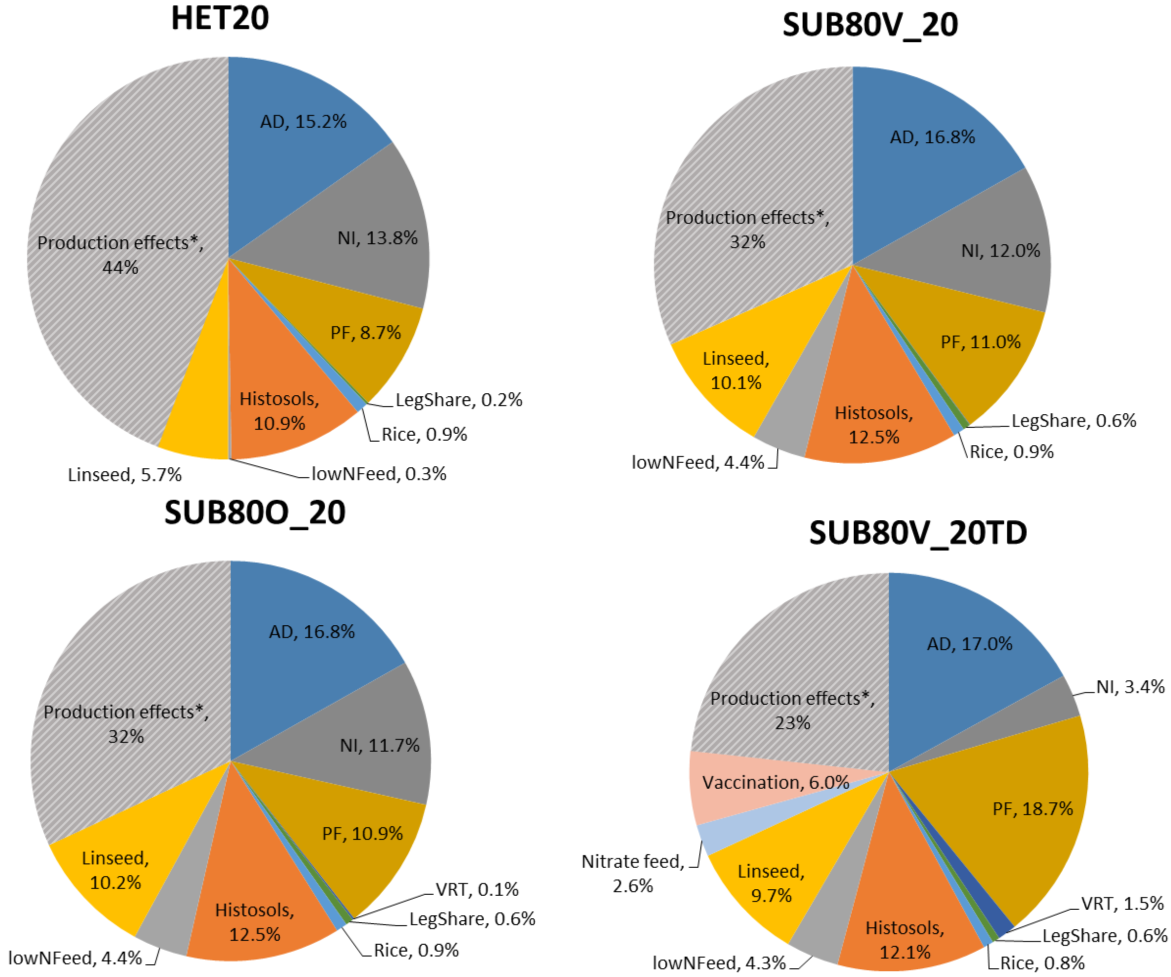
In the scenario assuming more rapid technological development (SUB80V_20TD), the contribution of precision farming to mitigation increases considerably (again at the expense of nitrification inhibitors). This is because of the assumption of an 'unrestricted' mitigation potential of the fertiliser measures in the SUB80V_20TD scenario, which makes precision farming more attractive than nitrification inhibitors. Furthermore, the additional two technologies available in the SUB80V_20TD scenario (vaccination against methanogenic bacteria in the rumen and nitrate as a feed additive) contribute 4.4 and about 2 million tonnes of CO_2 equivalents, respectively, to the emission reduction. With the contribution of the other technologies being about the same as in the SUB80V and SUB80O scenarios, this leads to a mitigation technologies contributing 77 % (55.8 million tonnes of CO_2 equivalents) to the total mitigation in SUB80V_20TD, compared with 68 % in the SUB80V (49.6 million tonnes of CO_2 equivalents) and SUB80O (49.4 million tonnes of CO_2 equivalents) scenarios.

Figure 23: Contribution of each technological mitigation option to total mitigation in the EU-28



* The mitigation effects linked to genetic improvement measures cannot be analysed in isolation and are included in the mitigation achieved by changes in production (see Box 2).

Figure 24: Relative contribution of each technological mitigation option to total mitigation in the EU-28



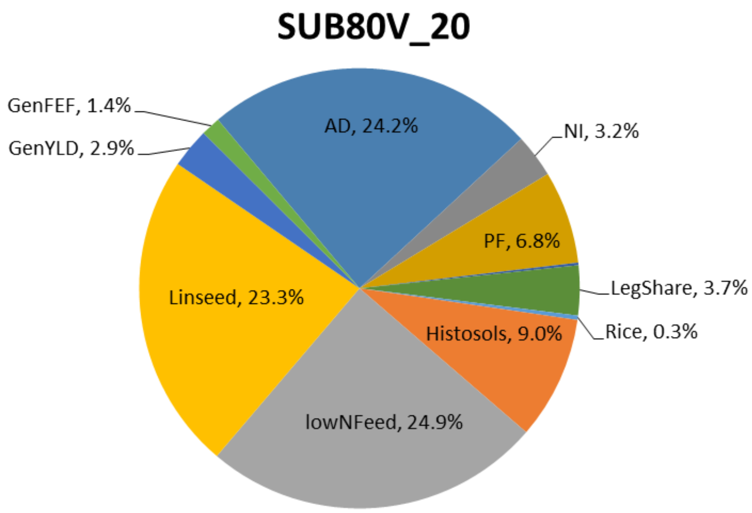
Note: AD = anaerobic digestion; NI = nitrification inhibitors; PF = precision farming; VRT = Variable Rate Technology.

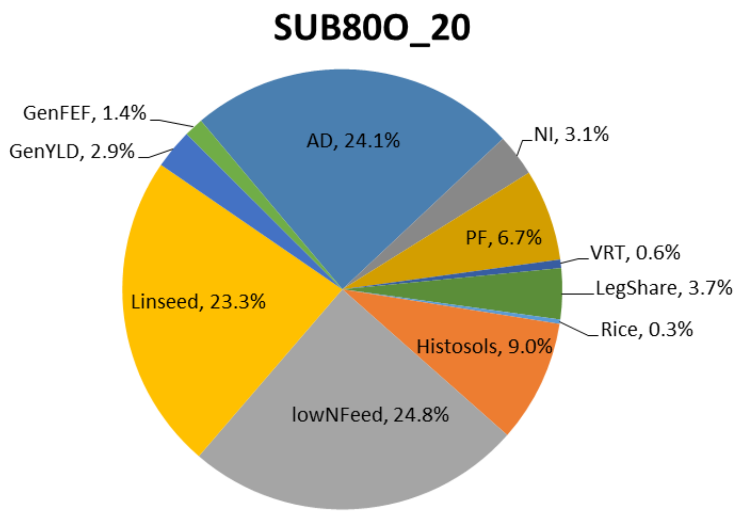
* The mitigation effects linked to genetic improvement measures cannot be analysed in isolation and are included in the mitigation achieved by changes in production (see Box 2).

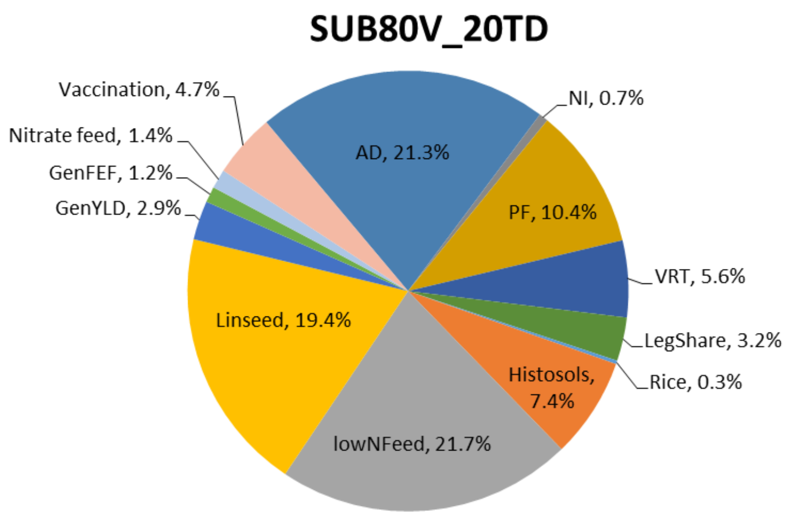
To get a better idea of the efficiency of the use of subsidies for the application of technological mitigation options, the contribution of each option to total mitigation (presented in Figure 23 and Figure 24) has to be compared with the share of this option in the total subsidies paid for mitigation technologies (presented in Figure 25). However, as noted below, there are limitations to the comparability of mitigation costs per technology and these figures should be considered with caution.

Finally, Figure 26 presents the share in total EU-28 subsidies for mitigation technologies and the contribution to total mitigation via technology adoption per Member State in the scenarios SUB80V_20 and SUB80V_20TD. There are some important points highlighted in this figure. First, the distribution of mitigation and the distribution of emissions are highly correlated, with greater mitigation occurring in countries with higher total emissions (correlation coefficient of 98 %). This pattern is somewhat less prominent when one focuses on the mitigation achieved via technology implementation (correlation coefficient of 94 %), showing that, in some countries, there is more mitigation via production shifts. Furthermore, the mix of technologies adopted for mitigation in some countries (e.g. Germany, Poland) is cheaper than in others (e.g. France, the Netherlands, Italy).

Figure 25: Share of technological mitigation options in total mitigation subsidies in the EU-28

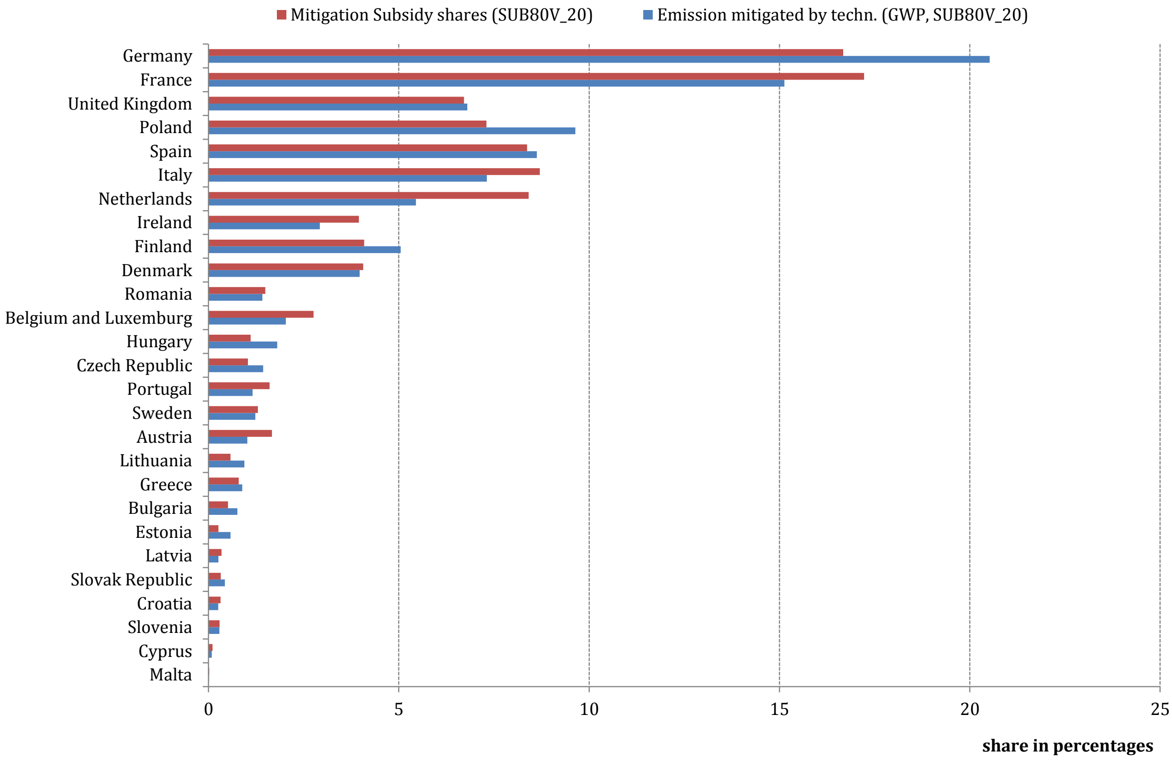


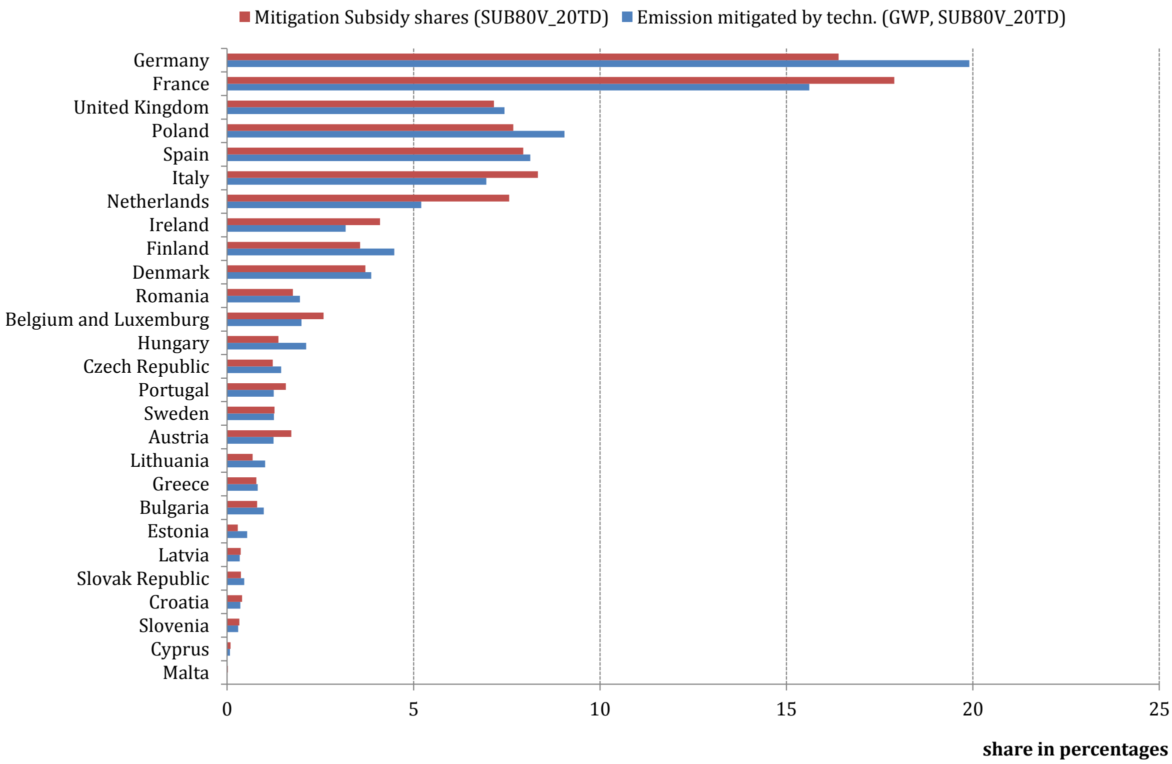




Note: AD = anaerobic digestion; NI = nitrification inhibitors; PF = precision farming; VRT = Variable Rate Technology.

Figure 26: Member States' share in total subsidies for mitigation technologies and contribution to total mitigation via technology adoption for selected scenarios





Note: The bar 'Emission mitigated by technology' does not include the mitigation effects from the measures related to genetic improvements, as it is not possible to disentangle the effects of the breeding programmes on total agricultural emissions from their related production effects (see Box 2).

6.1.6 Impact on the EU budget and economic welfare

From a budgetary point of view, two further main points can be derived from the scenario results (Table 18). The setting of targets without financial support (HET20) has no additional cost for the EU budget; however, as mentioned in the sections above, the impacts on domestic production and emission leakage can be substantial. The scenarios with subsidies for the adoption of mitigation technologies show major budgetary costs, as farmers are projected to widely adopt the technologies, which in turn helps to significantly reduce adverse impacts on domestic production and emission leakage.

Table 18: Total subsidies for mitigation technologies in the EU-28, 2030

Scenario		Total subsidies to mitigation technologies (Billon Euro)	Subsidy per tonne total CO_2eq mitigated (Euro/t)
Non-subsidised Voluntary Adoption of Technologies	HET20	NA	NA
Subsidised Voluntary Adoption of Technologies	SUB80V_20	13.6	188
Subsidised Mandatory/Voluntary Adoption of Technologies	SUB80O_20	13.7	188
Subsidised Voluntary Adoption of Technologies (with more rapid technological development)	SUB80V_20TD	15.6	215

The mitigation cost information shown in this report requires a series of disclaimers, mainly related to the treatment of the different technological mitigation measures and some modelling limitations. Here we stress some issues which should be kept in mind when interpreting the results of costs and related subsidies of the modelled GHG mitigation technologies:

- For the measures related to feed additives (nitrate and linseed) and low nitrogen feeding, the way in which subsidies are calculated is consistent, in the sense that subsidies are 80 % of net costs. However, net costs are simply assumed to be 50 % of gross costs, as we cannot identify with sufficient accuracy the cost savings associated with each measure independently. It appeared that the regional endogenous results on feed cost savings show a surprisingly high dispersion, such that it seemed preferable to base the modelling and economic accounting on simple but transparent assumptions. Therefore, the full endogenous costs in the regions might actually be lower (or higher) than the ones reported. As subsidies for the application of mitigation technologies are simply defined in relation to the assumed net costs, they are subject to the same reporting issues.
- For anaerobic digestion, the assumed costs are based on the literature. However, regarding subsidies, it has to be kept in mind that the subsidies were defined as 80 % of gross costs for this measure to avoid negative subsidies. This means that subsidies paid might be higher than those required in reality to achieve the same or a similar level of mitigation via this measure. This is important because anaerobic digestion represents a considerable part of the total subsidies paid.
- Regarding genetic improvements (i.e. 'increasing milk yields of dairy cows' and 'increasing ruminant feed efficiency'), costs have been assumed to be 20 % (10 %) of the immediate benefits. This appears to be a reasonable approximation for average fees and additional managerial burdens. However, assuming that this is homogeneous across all regions might be unrealistic. It has not been possible to differentiate these net costs regionally because (1) the calibration cost curve assumes a maximum possible implementation level of the measures without exceptions, even in regions where maximum implementation might not be reasonable, and (2) all measures interact such that an allocation of net costs is arbitrary or only locally valid if derived from the marginal values.

- The contribution of individual breeding measures to the total mitigation per scenario cannot be identified. This may not be a problem regarding the total costs and subsidies, but any analysis aiming to assess the cost-effectiveness of single measures suffers from this difficulty. We can, for example, see in the results of the mitigation scenarios that total emissions in the dairy sector indeed decrease. However, the net effect of the breeding programme on emissions cannot be quantified because of (1) changes in milk yields, (2) changes in activity levels driven by changes in prices and costs, and (3) changes due to the parallel application of other technologies in the dairy sector that all occur simultaneously, thus meaning it is not possible to disentangle the effects of the breeding programme on milk yields from the other effects.

At an aggregated level, these limitations are acceptable when providing an overall estimate of costs and subsidies. However, the technology-specific mitigation costs are not comparable across measures because of inconsistencies in the assumptions (e.g. VRT versus precision farming) and modelling limitations (e.g. feed measures).

From a sectoral perspective, economic welfare (i.e. only considering welfare linked to agricultural marketed outputs and not to, for example, environmental externalities) increases in the HET20 scenario (0.03 % or EUR 6 billion). This positive effect is caused by higher agricultural revenues and industry profits owing to the higher prices, which over-compensate the loss by consumers (i.e. money metric utility measure). On the other hand, total welfare decreases for the other scenarios, ranging from −0.02 % or EUR −3.4 billion (SUB80O_20) to −0.04 % or EUR −8.6 billion (SUBV80_20TD). The negative effect is the consequence of a much smoother increase in prices (i.e. lower profits by the food industry) and large costs for taxpayers due to the introduction of mitigation subsidies. It is important to note that we are computing welfare effects from only a partial equilibrium (sectoral) perspective, namely welfare effects linked to the European agricultural sector. Thus, additional effects on other sectors, for example induced by changes in consumer surplus or taxpayer costs, are not covered in this modelling approach (Table 19).

Table 19: Decomposition of welfare effects in the EU agricultural sector, 2030

	HET20	SUB80V_20	SUB80O_20	SUB80V_20TD
	Billion EUR (absolute difference to REF)			
Total welfare [1]	6.0	-3.4	-3.4	-8.6
Consumer surplus [2]	-20.9	-10.3	-10.5	-4.8
Agricultural income	21.7	21.6	21.8	14.3
…of which are subsidies for mitigation technologies	0.0	13.6	13.7	15.6

[1] Welfare effects linked to the European agricultural sector, calculated as the sum of consumer surplus plus producer surplus (agricultural income and profits from the processing industry) plus tariff revenues minus taxpayer costs. Additional effects on other sectors, for example induced by changes in consumer surplus or taxpayer costs, are not covered in this modelling approach.

[2] For consumers, CAPRI uses the money metric concept to measure consumer welfare. It can be broadly understood as a measurement of changes in the purchasing power of the consumer.

Table 19 indicates that total agricultural income increases in the HET20, SUB80V_20 and SUB80O_20 scenarios by approximately 10 %, and by less than 7 % in the SUBV80_20TD scenario. The changes in agricultural income can briefly be explained as follows:

- In HET20, the mitigation policy leads to decreasing agricultural activity levels (i.e. a decrease in production), which leads to an increase in agricultural commodity prices. The price effect is projected to outweigh the quantity effect, which leads to an increase in total agricultural income.

- In SUB80V_20 and SUB80O_20, the aforementioned decrease in agricultural production is reduced by the subsidies paid for the adoption of mitigation technologies (i.e. farmers adopt mitigation technologies and production is reduced by less). Therefore, agricultural prices increase less than in the HET20 scenario. On the other hand, farmers receive the subsidies for technologies, which in the end leads to roughly the same increase in total agricultural income as in HET20.
- SUB80V_20TD assumes more rapid technological development and, because of more (or more effective) mitigation technologies, production is reduced by less than in SUB80V_20 and SUB80O_20, or, in the case of milk, even increased compared with the REF scenario. This leads to significantly lower price increases than in the other scenarios, and in the case of milk even to a decrease in milk producer prices. The overall effect is a lower increase in total agricultural income than in the other scenarios. De facto, the income increase is lower than the subsidies paid for the technologies because part of these subsidies ‘compensate’ for the income losses resulting from price decreases.

Regarding the projected increase in EU-28 agricultural income, several issues have to be further highlighted: (1) farm income is not increasing proportionally to the subsidies paid for mitigation technologies; (2) income effects seem to vary considerably between both regions and agricultural sectors; and (3) the model used cannot provide results on the number of farmers/farms remaining active and benefitting from the potential increases in total agricultural income (i.e. the model does not consider farm-level structural change).

6.2 Results of the complementary scenarios

In addition to the main scenarios, four complementary scenarios were constructed. The HET15 and HET25 scenarios have the same assumptions as HET20, but, instead of a 20 % mitigation target for EU-28 agriculture, they have mitigation targets of 15 % and 25 %, respectively. In these scenarios, mitigation technologies are available for farmers, but no subsidy is paid for their application. The SUB80V_15 scenario follows the assumptions of the HET15 scenario but an 80 % subsidy is paid for the voluntary adoption of mitigation technologies. The 80 % subsidy for the voluntary adoption of mitigation technologies is also paid in the SUB80V_noT scenario; however, this scenario is run without any specific mitigation targets (see section 5.2).

In this section, we present the results of the complementary scenarios along with results of the HET20 scenario for comparison. The scenario results of HET20 are discussed in detail in the previous section 6.1. As a linear shifter is applied to get from the distribution key derived from the auxiliary Carb50 scenario to the mitigation efforts in the HET scenarios, the resulting effects in the HET scenario simulations are also quite linear among the three HET variants. Therefore, we discuss the results of and differences between the HET scenarios only briefly here. Impacts in the SUB80V_15 scenario and the differences between this and the HET15 scenario principally follow the patterns of the SUB80V_20 and HET20 scenarios (see section 6.1). On the other hand, the SUB80V_noT scenario shows a somewhat different pattern of effects from the HET scenarios, as no specific mitigation targets are assigned and the emission mitigation is actually achieved via the 80 % subsidy for the voluntary application of mitigation technologies, which constitutes an incentive for farmers to apply the technologies.

6.2.1 Changes in agricultural GHG emissions

By design, the HET15, HET20 and HET25 scenarios achieve their emission mitigation targets of 15 %, 20 % and 25 %, respectively, compared with 2005.[34] Differences in mitigation between the three scenarios, at both aggregated and Member State levels, are linear, reflecting the applied linear increase in mitigation targets. By contrast, although no specific reduction target is assigned, the SUB80V_noT scenario shows an emission reduction of almost 14 % compared with 2005, which is achieved by subsidising the mitigation technologies. This means that scenario SUB80V_noT achieves almost the same reduction as HET15, where binding mitigation targets are introduced at the Member State level, but no subsidies are paid for the application of mitigation technologies. Therefore, it seems adequate to look a bit closer at the differences between the SUB80V_noT and the HET15 scenarios. In almost all of the Member States, the mitigation achieved in SUB80V_noT is between 0.5 and 6 percentage points less than in the HET15 scenario. On the other hand, three Member States show higher emission reductions in SUB80V_noT than in HET15. By far the greatest difference can be observed in Finland, where the emission reduction in SUB80V_noT reaches 40.4 % compared with 22.5 % in HET15, whereas the differences in the Netherlands (−15.6 % in SUB80V_noT versus −11.2 % in HET15) and Italy (−11.5 % versus −10 %) are much smaller. The increase in mitigation efforts (compared with HET15) in these three countries is credited to an increase in the application of mitigation technologies, triggered by the subsidies paid, as this makes their application more profitable for farmers. In Finland and the Netherlands, this is the abandonment of histosol land (important in these countries), whereas the savings in Italy are triggered by various measures in the livestock sector.

Regarding the SUB80V_15 scenario, it can be seen in Table 20 that, with a reduction of 16.3 % compared with 2005, the envisaged aggregated EU-28 mitigation target of 15 % is actually overachieved. This is because, in several Member States, the income-

[34] For example, in HET15, the total mitigation compared with 2005 is (−12.8 %) + (−2.3 %) = −15.1 %.

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 target, with mitigation at almost 40 % in SUB80V_15 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).

Table 20: Changes in agriculture GHG emissions per EU Member State in 2030 (complementary scenarios)

	REF		HET15	HET20	HET25	SUB80V _noT	SUB80V _15
	1000t CO_2eq	%-change 2030 vs 2005	%-change compared to REF				
EU-28	399,514	-2.3	-12.8	-17.8	-22.8	-11.4	-14.0
Austria	6,907	1.1	-9.4	-14.4	-19.3	-6.4	-9.3
Belgium-Lux	8,129	-12.5	-12.9	-17.9	-22.7	-11.6	-13.2
Denmark	11,099	-0.5	-15.6	-20.6	-25.6	-12.6	-15.3
Finland	7,253	3.9	-22.5	-27.6	-32.6	-40.4	-39.6
France	69,389	-4.3	-11.6	-16.7	-21.7	-10.6	-13.1
Germany	60,797	-2.2	-14.7	-19.7	-24.7	-14.9	-16.8
Greece	6,174	-2.6	-8.8	-13.9	-18.9	-6.9	-8.9
Ireland	21,934	2.4	-10.1	-15.2	-20.2	-5.7	-10.0
Italy	25,213	-16.3	-10.0	-15.0	-19.9	-11.5	-11.3
Netherlands	18,621	-1.4	-11.2	-16.2	-21.1	-15.6	-15.4
Portugal	6,278	9.3	-13.5	-18.6	-23.6	-7.5	-13.4
Spain	35,272	11.6	-12.8	-17.8	-22.8	-10.1	-12.9
Sweden	7,126	-1.3	-10.5	-15.5	-20.5	-8.2	-10.5
United Kingdom	43,326	-9.8	-10.9	-16.0	-21.0	-7.4	-11.1
EU-15	327,518	-3.2	-12.3	-17.3	-22.3	-11.4	-13.7
Bulgaria	3,977	5.0	-10.5	-15.5	-20.4	-7.9	-10.4
Croatia	2,170	-4.2	-9.0	-14.0	-18.9	-4.7	-8.9
Cyprus	446	14.2	-10.8	-15.8	-20.8	-9.4	-10.9
Czech Republic	6,080	-0.1	-14.2	-19.2	-24.1	-10.7	-14.3
Estonia	1,661	28.5	-21.8	-26.8	-31.7	-15.1	-21.7
Hungary	6,335	1.9	-15.3	-20.3	-25.3	-11.8	-16.0
Latvia	2,505	21.7	-10.6	-15.5	-20.3	-4.5	-10.6
Lithuania	4,488	8.2	-14.8	-19.6	-24.5	-8.7	-14.6
Malta	62	-25.3	-8.3	-13.3	-18.2	-7.9	-8.2
Poland	28,928	6.1	-18.8	-23.8	-28.7	-15.7	-19.6
Romania	12,083	-13.0	-9.2	-14.2	-19.1	-5.3	-9.1
Slovak Republic	2,052	-4.8	-11.9	-16.9	-21.9	-8.7	-12.0
Slovenia	1,209	-1.4	-11.0	-15.9	-20.8	-10.5	-10.8
EU-N13	71,996	1.4	-14.9	-19.9	-24.8	-11.3	-15.3

Figure 27 and Figure 28 show that the increase in mitigation efforts in the EU in the HET scenarios goes along with an increase in emission leakage (i.e. an increase in emissions in non-EU countries). By contrast, the SUB80_noT scenario indicates that subsidising mitigation technologies without specific mitigation targets could even lead to negative emission leakage (i.e. a decrease in emissions) also outside the EU, actually augmenting the EU mitigation efforts with respect to global GHG emissions. The projected decrease in emissions outside the EU is due to the uptake of mitigation technologies in the EU, which in several cases has a positive effect on production efficiency (e.g. the breeding programmes), leading to an increase in EU production in some sectors (e.g. dairy products), replacing non-EU production that is indicated to have higher emission intensities than the corresponding EU products (Figure 29). Regarding the SUB80V_15 scenario, the wider application of mitigation technologies reduces the impact of emission leakage compared with HET15. As more mitigation is achieved via mitigation technologies than by changes in activity levels and, consequently, production and emissions increase less in non-EU countries, emission leakage decreases from 23 % in HET15 to 7 % in SUB80V_15.

Figure 27: Emission mitigation and leakage as a percentage of gross mitigation (complementary scenarios)

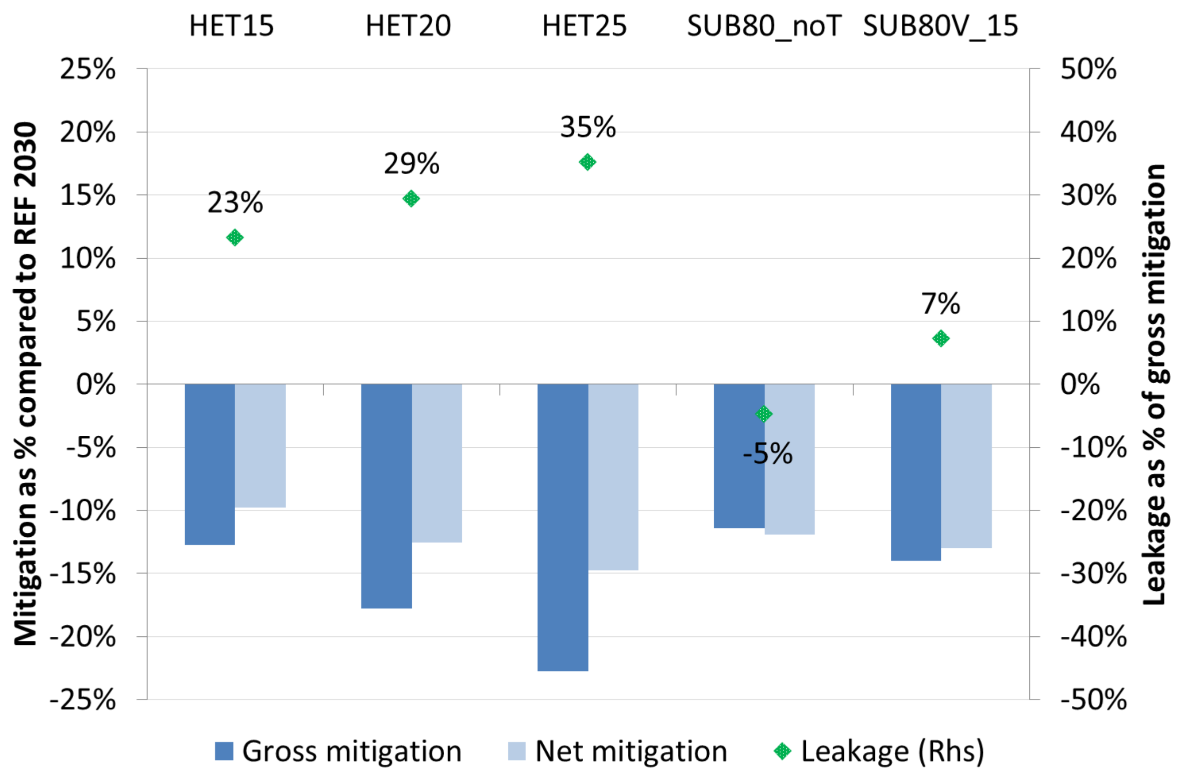


Figure 28: Geographical distribution of the increased emissions in the rest of the world (complementary scenarios)

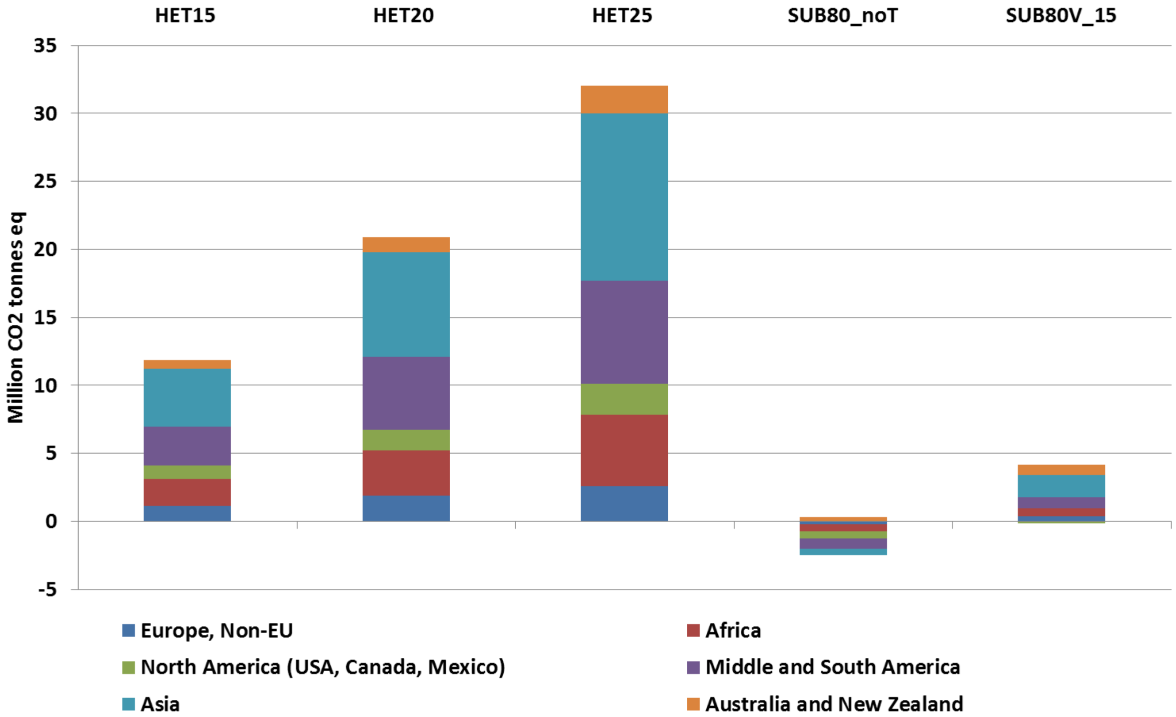
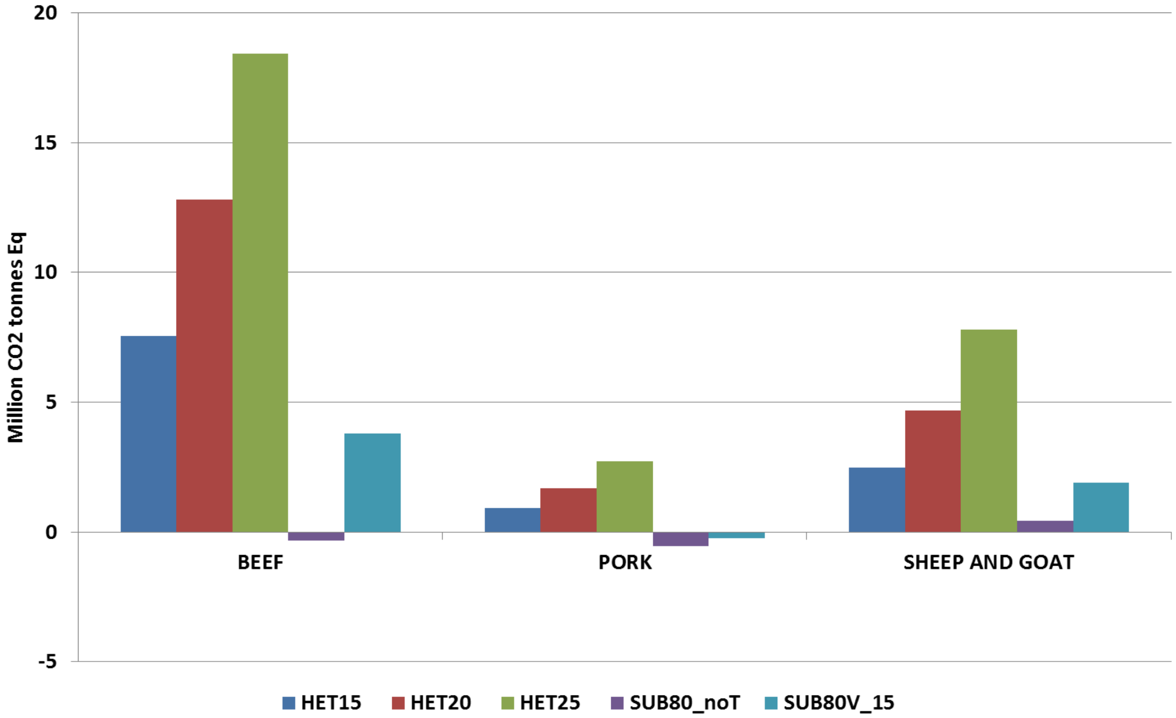


Figure 29: Change in emissions in the rest of the world by commodity (complementary scenarios)



6.2.2 Impact on agricultural production

Table 21 provides an overview of the effect of mitigation policies on agricultural activity levels. As already seen in the results for the scenarios with 20 % mitigation targets (see section 6.1), besides increases in set-aside and fallow land, beef production activities are most affected in the HET scenarios, followed by activities related to sheep and goats. Cereal area decreases between less than 3 % (1.5 million ha) in HET15 and 7 % (4 million ha) in HET25, whereas UAA decreases between less than 2 % (2.9 million ha) in HET15 and 5 % (9.3 million ha) in HET25. The picture changes when no specific mitigation targets are assigned but subsidies are paid for the uptake of mitigation technologies (SUB80V_noT). While, mainly due to the subsidised fallowing of histosols, set-aside and fallow land would increase by 27 % in the SUB80V_noT scenario (i.e. in a similar magnitude as in HET15), livestock activities would also increase. All meat activities are projected to increase in the SUB80V_noT scenario, regarding both herd size and supply at EU-28 level; for example, in beef meat activities, EU-28 herd size increases by 2.4 % and supply by 0.7 % (Member State results for beef herd size and production are presented in Table 22 pig meat activities in Table 24). Regarding dairy, herd sizes of dairy cows are decreasing (−1 %), whereas supply increases by 1.5 %, which is a direct consequence of the breeding programmes aiming to increase milk yields. The increase in milk production is particularly pronounced in Ireland, Romania and Bulgaria (about +7.5 % each) (Table 23). It has to be noted that cereal production is somewhat negatively affected in the SUB80V_noT scenario, as hectares and production are slightly reduced (mainly because of the increase in fallowing histosols) (see Table 25).

Comparing the HET15 with the SUB80V_15 scenario, the largest effects in both scenarios are, apart from increases in set-aside and fallow land, 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 SUB80V_15. In the crop sector, UAA decreases by 1.6 % (−2.9 million ha) in HET15 and by 0.7 % (1.3 million ha) in SUB80V_15, with cereal area decreases of 2.6 % (1.5 million ha) and 1.3 % (0.7 million ha), respectively. It can be noticed that, as in the SUB80V_noT scenario, also in the SUB80V_15 scenario an increase in EU-28 milk production is projected, even though dairy herd size decreases. This is again 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 %).

Table 21: Changes in area, herd size and supply for the EU-28 for activity aggregates (complementary scenarios)

	REF		HET15		HET20		HET25		SUB80V _noT		SUB80V _15	
	Hectares or herd size	Supply	Hectares or herd size	Supply	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	%-difference to REF									
Utilized agricultural area	180,898	na	-1.6	na	-3.1	na	-5.1	na	0.2	na	-0.7	na
Cereals	57,270	336,323	-2.6	-2.7	-4.4	-4.6	-6.9	-7.1	-0.5	-0.2	-1.3	-1.2
Oilseeds	12,040	34,137	-1.3	-1.4	-2.5	-2.5	-4.1	-4.1	-0.7	-0.8	-1.2	-1.3
Other arable crops	5,656	na	-0.7	na	-1.3	na	-2.1	na	-0.8	na	-0.9	na
Vegetables and Permanent crops	16,846	na	0.0	na	0.1	na	0.1	na	0.0	na	0.0	na
Fodder activities	82,230	42,261	-4.1	-6.0	-7.3	-10.8	-11.4	-16.1	-1.4	-2.4	-3.2	-5.3
Set aside and fallow land	6,856	na	30.8	na	46.4	na	68.4	na	27.2	na	33.4	na
Dairy cows	21,517	172,726	-1.9	-1.1	-3.4	-2.0	-5.2	-3.1	-0.9	1.5	-1.7	1.1
Beef meat activities	17,985	7,822	-9.1	-5.1	-16.1	-8.9	-24.4	-13.6	2.4	0.7	-2.4	-1.7
Pig fattening	233,781	22,653	-2.2	-2.2	-4.0	-4.1	-6.4	-6.5	2.3	2.3	1.6	1.6
Pig Breeding	11,897	238,852	-2.1	-2.2	-3.9	-4.0	-6.4	-6.4	2.3	2.3	1.6	1.6
Milk Ewes and Goat	76,341	4,502	-4.7	-3.4	-9.1	-7.1	-14.8	-12.0	0.4	0.1	-2.6	-2.1
Sheep and Goat fattening	44,235	754	-4.6	-4.4	-8.8	-8.3	-14.1	-13.3	0.5	0.6	-2.2	-2.1
Laying hens	545	8,244	-1.1	-0.9	-2.0	-1.7	-3.3	-2.7	-0.1	0.0	-0.4	-0.3
Poultry fattening	6,882	14,531	-0.6	-0.7	-1.2	-1.3	-2.1	-2.3	1.1	0.9	0.9	0.7

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

Table 22: Changes in beef herd size and production per EU Member State (complementary scenarios)

	REF		HET15		HET20		HET25		SUB80V _noT		SUB80V _15	
	Herd size	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.
	1000 hds	1000 t	%-difference to REF									
EU-28	17,985	7,822	-9.1	-5.1	-16.1	-8.9	-24.4	-13.6	2.4	0.7	-2.4	-1.7
Austria	419	193	-8.4	-5.4	-16.6	-10.7	-25.6	-16.6	2.7	1.1	-1.0	-1.4
Belgium-Lux	396	230	-4.9	-3.8	-10.7	-7.8	-18.3	-12.7	3.9	1.0	2.1	-0.5
Denmark	112	124	-18.8	-7.7	-39.9	-16.1	-64.7	-25.7	10.8	4.0	2.1	0.0
Finland	136	69	-10.9	-5.9	-12.6	-6.0	-15.2	-7.3	-2.1	-1.4	-3.9	-1.4
France	5,029	1,751	-8.2	-5.6	-14.4	-10.0	-21.9	-15.4	1.2	0.2	-2.7	-2.5
Germany	1,231	996	-8.6	-4.8	-14.9	-8.5	-22.6	-13.2	4.9	1.5	0.7	-0.7
Greece	217	51	-10.3	-3.3	-25.0	-8.1	-44.8	-14.1	0.0	0.6	-4.1	-1.0
Ireland	1,977	616	-8.2	-4.7	-13.5	-7.5	-20.3	-10.8	4.0	2.6	-1.5	-0.7
Italy	898	594	-3.1	-2.3	-6.6	-4.9	-12.9	-9.7	1.7	0.6	1.8	0.8
Netherlands	121	413	-13.6	-4.8	-23.7	-8.4	-34.1	-12.2	-3.0	-0.7	-1.2	-1.1
Portugal	592	132	-8.7	-6.3	-14.3	-9.9	-21.2	-14.0	3.4	1.0	-2.9	-3.4
Spain	2,097	687	-9.9	-3.4	-18.5	-6.1	-29.8	-9.9	1.1	0.0	-5.3	-2.2
Sweden	332	132	-8.4	-5.4	-15.3	-9.7	-24.6	-15.3	3.5	1.7	0.0	-0.9
UK	2,780	890	-9.2	-4.9	-15.5	-8.1	-21.6	-10.8	2.3	0.5	-3.0	-2.3
EU-15	16,336	6,879	-8.5	-4.7	-15.0	-8.4	-22.9	-12.8	2.2	0.8	-2.2	-1.5
Bulgaria	44	24	-15.0	-2.5	-31.5	-5.7	-47.8	-8.3	6.1	-2.0	-3.4	-2.7
Croatia	65	45	-30.0	-9.2	-47.4	-14.3	-54.1	-21.7	4.8	1.6	-9.1	-2.6
Cyprus	4	5	-5.6	-3.1	-13.9	-7.4	-22.2	-10.7	2.8	0.9	0.0	-0.2
Czech Republic	317	82	-21.3	-9.4	-35.3	-15.5	-51.5	-21.6	5.9	1.7	-6.2	-3.8
Estonia	20	14	-30.0	-7.7	-49.0	-12.6	-67.5	-16.7	11.0	1.0	-6.5	-3.2
Hungary	124	50	-19.3	-7.7	-34.5	-13.4	-50.1	-19.9	3.9	1.0	-8.8	-4.2
Latvia	27	32	-17.0	-8.4	-28.0	-13.1	-39.9	-17.4	8.1	3.4	-5.5	-3.9
Lithuania	68	46	-20.6	-8.3	-36.6	-14.6	-53.8	-20.3	6.8	1.7	-8.1	-4.3
Malta	1	1	-7.7	-4.1	-15.4	-12.4	-30.8	-20.6	0.0	-1.0	0.0	-2.1
Poland	712	466	-12.6	-7.9	-22.8	-14.0	-32.6	-20.6	2.5	0.1	-3.5	-3.8
Romania	79	106	-11.3	-5.8	-23.4	-11.8	-38.4	-18.7	1.8	-0.5	-5.9	-4.3
Slovak Republic	24	18	-11.9	-3.7	-20.8	-7.4	-29.2	-10.0	3.0	0.1	-7.6	-3.2
Slovenia	164	53	-10.9	-4.8	-15.2	-5.5	-25.5	-8.5	4.6	1.0	4.4	1.9
EU-N13	1,648	943	-15.9	-7.5	-27.5	-13.0	-39.7	-19.0	4.0	0.5	-4.3	-3.5

Note: Total supply of beef includes beef from suckler cows, heifers, bulls, dairy cows and calves (carcass weight).

Table 23: Changes in dairy herd size and milk production per EU Member State (complementary scenarios)

	REF		HET15		HET20		HET25		SUB80V _noT		SUB80V _15	
	Herd size	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.
	1000 hds	1000 t	%-difference to REF									
EU-28	21,517	172,726	-1.9	-1.1	-3.4	-2.0	-5.2	-3.1	-0.9	1.5	-1.7	1.1
Austria	497	3,949	-1.6	-1.1	-3.1	-2.2	-4.8	-3.2	-0.8	1.7	-1.5	1.2
Belgium-Lux	565	4,431	-1.1	-0.5	-2.6	-1.3	-4.3	-2.3	-0.8	1.9	-1.0	1.9
Denmark	598	5,971	-1.9	-1.8	-4.4	-4.1	-7.2	-6.9	1.1	1.2	0.1	0.3
Finland	226	2,361	-1.9	-1.9	-2.1	-2.0	-2.8	-2.7	-0.8	-0.5	-1.6	-1.4
France	3,619	28,269	-1.4	-0.9	-2.6	-1.7	-4.0	-2.7	-1.2	1.4	-1.8	0.9
Germany	4,020	36,161	-1.5	-1.1	-2.7	-2.0	-4.2	-3.1	-0.5	0.5	-1.2	0.0
Greece	81	593	-0.2	1.4	-0.9	2.1	-1.7	2.7	-0.5	2.6	-0.4	3.5
Ireland	1,317	7,530	-2.0	0.6	-3.3	0.4	-4.7	-0.1	-1.4	7.5	-2.4	6.6
Italy	1,650	12,398	-0.9	-0.2	-2.0	-0.6	-4.1	-2.0	-0.8	2.3	-0.5	2.8
Netherlands	1,527	14,719	-1.9	-1.8	-3.2	-3.0	-4.7	-4.5	-0.9	-0.1	-0.6	0.2
Portugal	201	2,063	-2.8	-2.0	-3.7	-2.5	-5.1	-3.2	-0.9	0.4	-2.6	-1.0
Spain	690	6,453	-0.9	-0.6	-1.1	-0.6	-1.3	-0.4	-0.8	0.2	-1.2	0.0
Sweden	298	3,022	-1.4	-1.2	-2.5	-2.2	-3.9	-3.4	0.2	0.7	-0.5	0.1
UK	1,863	17,027	-1.7	-1.4	-2.9	-2.3	-3.9	-2.9	-0.5	0.8	-1.3	0.1
EU-15	17,149	144,947	-1.5	-1.0	-2.7	-1.8	-4.2	-2.9	-0.7	1.2	-1.3	0.9
Bulgaria	229	1,036	-2.5	-1.6	-5.8	-4.1	-9.3	-6.4	-0.8	7.1	-2.2	6.4
Croatia	153	755	-2.1	-0.6	-3.2	-0.6	-6.1	-1.7	-1.9	1.0	-2.9	0.6
Cyprus	23	209	0.0	0.1	-0.9	-0.1	-1.7	-0.3	-0.9	0.5	-0.9	0.6
Czech Republic	249	2,379	-1.4	-1.1	-2.6	-2.1	-3.9	-3.1	-0.8	0.1	-1.7	-0.7
Estonia	104	951	-1.4	-1.2	-2.2	-1.6	-3.2	-2.2	-0.7	0.4	-1.5	-0.3
Hungary	174	1,508	-3.0	-2.7	-5.7	-5.0	-9.3	-8.4	-0.6	1.3	-2.8	-0.8
Latvia	179	1,109	-1.9	0.5	-3.0	1.1	-4.3	2.3	-1.3	1.9	-3.1	1.9
Lithuania	317	2,028	-2.9	-1.5	-5.2	-2.7	-7.7	-4.0	-0.8	2.1	-2.9	0.8
Malta	5	41	0.0	0.6	0.0	0.2	-2.2	-0.4	0.0	1.8	0.0	2.3
Poland	2,054	12,831	-4.1	-1.9	-7.1	-3.3	-10.8	-4.9	-1.4	2.9	-3.5	1.8
Romania	697	3,530	-4.0	0.0	-7.9	-0.8	-12.3	-2.6	-2.2	7.4	-4.5	6.1
Slovak Republic	93	753	-2.4	-1.4	-5.7	-4.0	-9.6	-6.9	-0.8	1.4	-2.3	0.3
Slovenia	91	648	-1.0	0.2	-1.3	0.9	-2.5	1.1	-1.4	2.9	-1.3	3.6
EU-N13	4,368	27,780	-3.4	-1.4	-6.1	-2.5	-9.4	-4.0	-1.3	3.0	-3.2	2.0

Table 24: Changes in pig numbers and pork production per EU Member State (complementary scenarios)

	REF		HET15		HET20		HET25		SUB80V _noT		SUB80V _15	
	Herd size	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.
	1000 hds	1000 t	%-difference to REF									
EU-28	245,679	23,300	-2.2	-2.2	-4.0	-4.1	-6.4	-6.5	2.3	2.3	1.6	1.6
Austria	3,706	418	-3.2	-3.2	-6.6	-6.6	-9.9	-9.9	1.3	1.3	-0.8	-0.8
Belgium-Lux	7,685	860	-2.4	-2.4	-5.2	-5.2	-8.6	-8.6	2.0	2.0	1.6	1.6
Denmark	28,168	2,243	-2.3	-2.3	-5.0	-5.0	-7.9	-7.9	3.9	3.9	2.3	2.3
Finland	2,295	213	0.1	0.1	2.3	2.4	5.6	5.6	4.1	4.1	5.3	5.3
France	23,451	2,167	-4.0	-4.0	-7.2	-7.2	-10.5	-10.6	5.1	5.2	3.4	3.4
Germany	47,522	5,303	-3.4	-3.4	-6.4	-6.4	-8.9	-9.0	1.4	1.4	0.5	0.5
Greece	1,821	93	0.0	0.2	-0.2	0.1	0.3	0.8	3.8	3.6	3.5	3.3
Ireland	3,635	266	-0.6	-0.6	0.5	0.5	2.9	2.8	6.4	6.4	5.7	5.7
Italy	14,208	1,904	-0.9	-0.9	-1.1	-1.1	-3.2	-3.2	4.2	4.2	5.1	5.1
Netherlands	18,520	1,418	-2.3	-2.2	-4.1	-4.1	-6.5	-6.5	1.4	1.4	1.8	1.8
Portugal	3,820	284	-0.8	-0.8	-0.9	-0.9	-0.5	-0.5	1.9	1.9	0.8	0.8
Spain	47,196	4,088	-1.1	-1.1	-1.8	-1.8	-5.1	-5.1	1.9	1.8	2.0	2.0
Sweden	2,014	193	-0.5	-0.5	-0.5	-0.5	-0.4	-0.3	3.2	3.2	3.0	3.0
UK	8,673	645	-1.0	-1.0	-1.1	-1.1	-0.5	-0.5	0.0	0.0	-0.9	-0.9
EU-15	212,713	20,093	-2.2	-2.3	-4.1	-4.2	-6.5	-6.7	2.6	2.6	2.0	2.0
Bulgaria	209	12	0.7	0.7	0.9	0.8	1.9	1.8	1.3	1.3	1.5	1.4
Croatia	2,882	187	-0.5	-0.5	0.1	0.1	-0.9	-0.9	0.5	0.5	-0.1	-0.1
Cyprus	796	62	-2.0	-1.9	-4.3	-4.3	-6.5	-6.4	3.7	3.7	3.2	3.2
Czech Republic	810	70	0.2	0.2	1.1	1.1	2.7	2.6	3.8	3.8	4.1	4.1
Estonia	483	51	-0.3	-0.3	1.0	0.9	3.1	3.0	2.4	2.4	2.1	2.1
Hungary	3,048	288	-2.2	-2.1	-4.0	-3.9	-6.9	-6.8	1.5	1.5	-0.3	-0.3
Latvia	352	38	-1.1	-1.0	-0.9	-0.9	0.1	0.2	1.9	1.8	0.6	0.5
Lithuania	445	41	-0.7	-0.7	-0.6	-0.6	0.3	0.4	1.5	1.5	0.5	0.5
Malta	78	6	0.4	0.5	-0.9	-0.8	-2.6	-2.1	10.8	10.2	11.9	11.3
Poland	19,370	1,964	-2.8	-2.8	-4.9	-4.9	-7.4	-7.4	0.2	0.2	-1.7	-1.7
Romania	3,934	427	-0.3	-0.3	-1.3	-1.3	-2.5	-2.5	0.7	0.7	-0.3	-0.3
Slovak Republic	464	52	0.5	0.6	-2.5	-2.3	-5.5	-5.4	1.6	1.6	2.5	2.7
Slovenia	94	9	0.3	0.4	2.0	2.0	3.2	3.4	1.4	1.2	2.6	2.3
EU-N13	32,966	3,207	-2.0	-2.0	-3.5	-3.6	-5.5	-5.6	0.7	0.7	-0.8	-0.8

Table 25: Changes in cereal area and production per EU Member State (complementary scenarios)

	REF		HET15		HET20		HET25		SUB80V _noT		SUB80V _15	
	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.
	1000 ha	1000 t	%-difference to REF									
EU-28	57,271	336,323	-2.6	-2.7	-4.4	-4.6	-6.9	-7.1	-0.5	-0.2	-1.3	-1.2
Austria	787	4,999	-0.6	-1.0	-1.1	-1.7	-1.6	-2.1	0.6	0.9	0.4	0.5
Belgium-Lux	388	3,822	-1.2	-1.4	-3.6	-3.6	-8.9	-8.5	3.2	3.3	2.9	2.9
Denmark	1,381	9,909	-0.1	-0.3	0.8	0.4	2.0	1.5	2.2	2.2	2.9	2.8
Finland	1,149	4,964	-6.3	-5.8	-9.6	-8.7	-11.8	-10.5	-13.1	-12.6	-13.3	-12.7
France	9,595	73,941	-1.8	-1.7	-3.2	-3.0	-5.2	-4.6	0.1	0.3	-0.4	-0.2
Germany	6,515	51,645	-4.9	-4.6	-8.0	-7.4	-12.1	-11.0	-2.5	-2.0	-4.0	-3.4
Greece	805	4,251	-1.8	-2.3	-3.9	-5.2	-7.0	-8.7	0.2	0.3	-0.3	-0.5
Ireland	203	1,993	3.3	3.1	3.9	3.9	3.1	3.5	4.1	4.4	6.2	6.3
Italy	3,273	20,292	-1.9	-1.8	-3.8	-3.5	-7.7	-7.7	0.7	0.8	0.5	0.7
Netherlands	207	1,946	-0.3	0.4	-0.8	0.7	-0.3	2.3	-11.3	-9.0	-11.1	-8.7
Portugal	211	1,156	-3.9	-3.6	-6.0	-5.6	-8.1	-7.3	1.2	1.2	-1.1	-1.1
Spain	6,115	23,056	-1.8	-2.8	-3.1	-5.0	-5.0	-7.6	0.7	1.2	0.2	0.0
Sweden	854	4,762	-2.6	-2.3	-4.7	-4.1	-7.3	-6.2	1.0	1.1	0.4	0.5
UK	3,050	22,224	-0.5	-0.4	-0.4	-0.2	-0.6	0.1	-0.5	-0.2	-0.3	-0.1
EU-15	34,533	228,960	-2.3	-2.3	-3.9	-3.9	-6.2	-6.0	-0.6	-0.3	-1.1	-0.9
Bulgaria	1,919	8,913	-2.7	-3.2	-7.1	-7.6	-13.1	-13.2	0.3	0.5	-0.9	-1.0
Croatia	542	3,869	-2.6	-2.6	-4.0	-4.0	-6.6	-6.5	0.5	0.6	-0.6	-0.6
Cyprus	30	65	-1.7	-1.5	-3.4	-3.1	-5.4	-4.7	0.3	0.3	-0.3	-0.3
Czech Republic	1,674	9,655	-2.8	-3.7	-4.8	-6.6	-8.4	-11.0	0.1	0.4	-1.2	-1.4
Estonia	324	1,393	-4.9	-4.7	-5.1	-5.0	-5.2	-4.9	-0.8	-0.6	-2.1	-1.9
Hungary	2,846	17,303	-2.2	-2.1	-3.9	-3.9	-6.2	-6.1	-0.2	-0.1	-1.3	-1.2
Latvia	584	2,201	-1.0	-1.5	-1.6	-2.4	-2.2	-2.9	0.8	0.9	0.0	-0.3
Lithuania	1,059	5,412	-2.4	-3.8	-3.5	-6.1	-4.4	-7.9	1.8	1.9	0.3	-0.7
Malta	4	20	-2.5	-1.2	-5.0	-2.7	-5.0	-4.5	0.0	-0.5	-2.5	-1.0
Poland	7,791	34,572	-4.2	-5.3	-6.1	-8.2	-8.8	-12.1	-1.1	-0.6	-2.5	-2.8
Romania	5,140	19,553	-2.3	-2.3	-4.7	-4.6	-7.8	-7.2	0.3	0.4	-1.3	-1.3
Slovak Republic	720	3,635	-1.3	-1.2	-3.3	-3.4	-6.5	-6.3	0.2	0.2	-0.5	-0.4
Slovenia	106	771	-7.0	-6.1	-9.6	-8.3	-9.8	-8.3	-8.2	-6.9	-8.5	-7.0
EU-N13	22,738	107,363	-3.0	-3.5	-5.1	-6.1	-8.0	-9.3	-0.2	0.0	-1.6	-1.7

6.2.3 Impact on EU producer and consumer prices

The impacts on EU producer (Table 26) and consumer (Table 27) prices in the complementary scenarios are in line with the production effects in each of the scenarios. As seen in previous sections, with rising mitigation targets in the HET scenarios, mitigation efforts are increasingly achieved by a reduction in agricultural activity levels, which in turn leads to increases in prices. Accordingly, price increases are highest for beef production in the HET scenarios, followed by increases in milk prices. On the other hand, production increases triggered in the SUB80V_noT scenario lead to a decrease in commodity prices, most pronounced for cow milk producer prices (–6.6 %). Exceptions can be seen in the crop sector, where a slight production decrease leads to small increases in some producer prices.

Concerning the SUB80_15 scenario, as impacts on production levels are generally lower than in the HET15 scenario, prices also increase 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 SUB80V_15 scenario (particularly pronounced in the milk prices).

Table 26: Change in EU producer prices (complementary scenarios)

	REF	HET15	HET20	HET25	SUB80V_noT	SUB80V_15
	EUR/t	%-difference to REF				
Cereals	195	1.0	1.8	3.8	0.6	0.8
Oilseeds	401	1.3	2.2	4.0	-1.0	-0.6
Other arable field crops	92	1.7	3.0	5.4	0.7	1.0
Vegetables and Permanent crops	853	0.5	1.0	1.7	0.5	0.6
Beef	4,363	13.4	25.9	43.8	-1.6	4.0
Pork meat	1,849	4.4	8.8	15.5	-2.7	-1.3
Sheep and goat meat	6,614	5.8	11.4	17.5	-0.6	2.4
Poultry meat	1,885	2.1	4.0	6.8	-1.0	-0.2
Cow and buffalo milk	429	6.6	12.3	19.7	-6.6	-3.9
Sheep and goat milk	962	4.5	9.0	15.0	-4.1	-1.7
Eggs	1,534	2.1	4.0	6.7	0.0	0.7

Table 27: Change in EU consumer prices (complementary scenarios)

	REF	HET15	HET20	HET25	SUB80V_noT	SUB80V_15
	EUR/t	%-difference to REF				
Cereals	3,281	0.1	0.1	0.2	0.0	0.0
Oilseeds	3,162	0.1	0.2	0.4	-0.1	0.0
Other arable field crops	1,279	0.1	0.2	0.3	0.1	0.2
Vegetables and Permanent crops	2,355	0.1	0.1	0.2	0.0	0.0
Beef	9,368	6.2	12.1	20.5	-0.7	1.9
Pork meat	6,417	1.3	2.6	4.6	-0.8	-0.4
Sheep and goat meat	11,179	2.8	5.5	8.3	-0.2	1.2
Poultry meat	4,322	0.9	1.7	2.9	-0.4	-0.1
Eggs	4,636	0.7	1.3	2.2	0.0	0.2
Butter	4,507	3.9	7.1	11.3	-3.6	-2.0
Cheese	6,477	2.0	3.8	6.2	-2.0	1.2

6.2.4 Impact on EU imports, exports and net trade position

Following the production and price developments, the net trade position worsens in the HET scenarios and the largest changes are indicated for meat products; however, for some of them, trade represents only a small proportion of domestic production. Again, the effects are generally reversed when a subsidy for the uptake of mitigation technologies is paid without specific mitigation targets in place (SUB80V_noT). The EU net trade position also improves for some agricultural commodities in the SUB80V_15 scenario. In line with the increased production levels in SUB80V_15, EU exports increase, especially for dairy products, albeit less than in the SUB80V_noT scenario. Moreover, it can be observed that cereal trade in SUB80V_15 is affected more than in HET15, even though the latter scenario shows a lower degree of effects on EU production levels. This can be explained by increased EU domestic feed use owing to the production effects triggered in the SUB80V_15 scenario (which is again more pronounced in the SUB80V_noT scenario).

Table 28: Changes in EU imports, exports and net trade position for aggregate activities according to the scenarios (complementary scenarios)

	REF			HET15			HET20			HET25			SUB80V_noT			SUB80V_15		
	Imports	Exports	Net trade	Imports	Exports	Net trade	Imports	Exports	Net trade	Imports	Exports	Net trade	Imports	Exports	Net trade	Imports	Exports	Net trade
	1000 t			%-diff to REF		1000 t	%-diff to REF		1000 t	%-diff to REF		1000 t	%-diff to REF		1000 t	%-diff to REF		1000 t
Cereals	6,430	53,921	47,491	1.0	-2.0	46,328	2.8	-4.0	45,145	9.2	-8.7	42,203	3.3	-1.9	46,252	2.9	-2.2	46,101
Oilseeds	17,795	5,268	-12,528	0.1	-3.1	-12,714	0.2	-5.5	-12,852	0.6	-9.2	-13,124	-1.4	0.7	-12,240	-1.5	-0.3	-12,283
Other arable field crops	1,759	3,149	1,390	-1.5	-0.9	1,386	-3.1	-1.5	1,396	-4.4	-2.6	1,384	-5.1	-1.6	1,428	-6.3	-1.3	1,460
Vegetables and Permanent crops	25,368	6,399	-18,969	0.7	-0.5	-19,170	1.3	-1.0	-19,356	2.2	-1.7	-19,644	0.5	-0.7	-19,135	0.7	-0.9	-19,203
Oils	12,225	1,695	-10,530	-0.2	-0.3	-10,517	-0.3	-0.6	-10,506	-0.3	-1.0	-10,509	-1.4	0.1	-10,363	-1.4	0.0	-10,359
Oil cakes	23,859	5,102	-18,757	-6.7	4.5	-16,937	-12.8	8.9	-15,240	-20.3	14.5	-13,168	-18.0	11.5	-13,866	-20.8	14.0	-13,073
Beef	201	358	157	21.0	-39.5	-27	28.5	-65.3	-134	53.2	-82.9	-247	-1.4	6.4	183	5.5	-17.0	85
Pork	298	2,153	1,855	24.6	-21.4	1,321	51.3	-38.0	883	93.8	-57.4	340	-12.5	15.2	2,220	-6.2	7.5	2,034
Sheep and goat meat	372	51	-321	8.4	-31.7	-368	17.6	-52.3	-413	34.9	-66.1	-484	-0.4	0.2	-319	4.1	-17.8	-345
Poultry meat	351	1,690	1,340	10.3	-9.9	1,136	24.7	-18.3	943	48.1	-29.4	675	-0.2	3.7	1,404	0.1	-0.3	1,335
Dairy products	149	3,843	3,694	5.4	-4.6	3,508	11.6	-8.4	3,352	20.9	-13.2	3,155	-5.0	4.7	3,880	-3.1	2.7	3,802

Note: Net trade = exports – imports.

6.2.5 Adoption of technological mitigation options and associated subsidies

Table 29 shows that the level of emission reduction achieved via technological mitigation options decreases with an increase in the mitigation target (i.e. the level of mitigation achieved via a change in production levels and production mix increases the higher the mitigation target is set). Again, it has to be highlighted that the presented level of mitigation achieved via mitigation technologies does not cover the mitigation achieved via the measures related to genetic improvements, as it is not possible to disentangle their mitigation effects from the related production effects (see Box 2). Nonetheless, a deeper look into the scenario results shows that methane emissions from enteric fermentation in dairy cows decrease in all scenarios, including the SUB80V_noT and SUB80_15 scenarios, even though in these two scenarios an increase in total milk production is projected. However, this decrease in enteric fermentation in dairy cows has to be seen in conjunction with all measures affecting methane emissions from enteric fermentation (i.e. together with linseed as a feed additive, the application of which is, for example, considerably higher in the SUB80V_15 than in the HET15 scenario).

Table 29: Proportion of emission reduction achieved via the mitigation technologies and via changes in production levels and production shifts (complementary scenarios)

	HET15	HET20	HET25	SUB80V _noT	SUB80V _15
	Share in total GHG emission reduction				
Mitigation technologies*	64%	56%	47%	99%	85%
Change in production**	36%	44%	53%	1%	15%

* Does not include the mitigation effects from the measures related to genetic improvements, as it is not possible to disentangle the effects of the breeding programmes on total agricultural emissions from their related production effects (see Box 2).

** This covers the proportion of emission reduction that cannot be directly attributed to technological mitigation options (i.e. mitigation through changes in production levels and production mix, and also the mitigation effects from the measures related to genetic improvements).

Even though the proportion of emission reduction achieved via technological mitigation options is decreasing, adoption of mitigation technologies generally increases in the HET scenarios along with the increase in mitigation targets (Table 30). However, for anaerobic digestion, nitrification inhibitors and rice measures, the adoption rates are about the same in the HET20 and HET25 scenarios, as their maximum possible shares of implementation are already (almost) reached in HET20. Moreover, implementation shares of precision farming, VRT and low nitrogen feed are also almost the same in the HET20 and HET25 scenarios, which indicates that, for these technologies, the cost-effective implementation does not increase substantially with a rise in the mitigation target once a certain share of adoption is reached. In the SUB80V_noT scenario, mitigation technologies are applied purely based on income-maximising grounds (i.e. a specific technology will be applied to an agricultural activity if the marginal revenue of the activity plus the subsidies exceeds the costs of production). In a sense, emission reduction is a positive side effect and not guaranteed like in the case of a (binding) emission target in the HET scenarios. Thus, a higher implementation in the SUB80V_noT scenario than in the HET scenarios indicates positive income effects for the farmers. With respect to the SUB80V_15 scenario, the subsidies paid for the adoption of mitigation technologies generally increases their implementation rate compared with the HET15 scenario. The exceptions are nitrification inhibitors, which are applied more in the HET15 than in the SUB80V_15 scenario. This is due to the increased application of precision farming once subsidies are paid, which is indicated to be more effective than the application of nitrification inhibitors (i.e. it generates higher income (from subsidies) than the application of nitrification inhibitors).

Table 30: Implementation and maximum possible shares of technologies at the EU level in the complementary scenarios (% of agricultural area or herd sizes)

Technology	Implementation share					Maximum possible share				
	HET15	HET20	HET25	SUB80 _noT	SUB80 _15	HET15	HET20	HET25	SUB80 _noT	SUB80 _15
Anaerobic digestion	25%	30%	32%	33%	33%	33%	33%	34%	33%	33%
Better fertilization timing	0%	0%	0%	0%	0%	7%	7%	7%	7%	7%
Nitrification inhibitors	53%	57%	58%	33%	44%	60%	60%	60%	60%	60%
Precision farming	18%	24%	27%	34%	33%	58%	58%	58%	58%	58%
Variable Rate Technology	0%	0%	0%	2%	2%	9%	9%	9%	9%	9%
Higher legume share	9%	19%	30%	79%	79%	100%	100%	100%	100%	100%
Rice measures	71%	98%	100%	72%	75%	100%	100%	100%	100%	100%
Fallowing histosols	57%	69%	80%	77%	78%	100%	100%	100%	100%	100%
Low nitrogen feed	0%	1%	3%	33%	34%	55%	56%	57%	55%	55%
Feed additives: linseed	7%	13%	19%	16%	19%	29%	29%	29%	29%	29%
Increasing milk yields of dairy cows	8%	15%	24%	50%	54%	100%	100%	100%	100%	100%
Increasing ruminant feed efficiency	52%	72%	85%	45%	62%	100%	100%	100%	100%	100%
Feed additives: nitrate	na	na	na	na	na	na	na	na	na	na
Vaccination (methanogenic bacteria in the rumen)	na	na	na	na	na	na	na	na	na	na

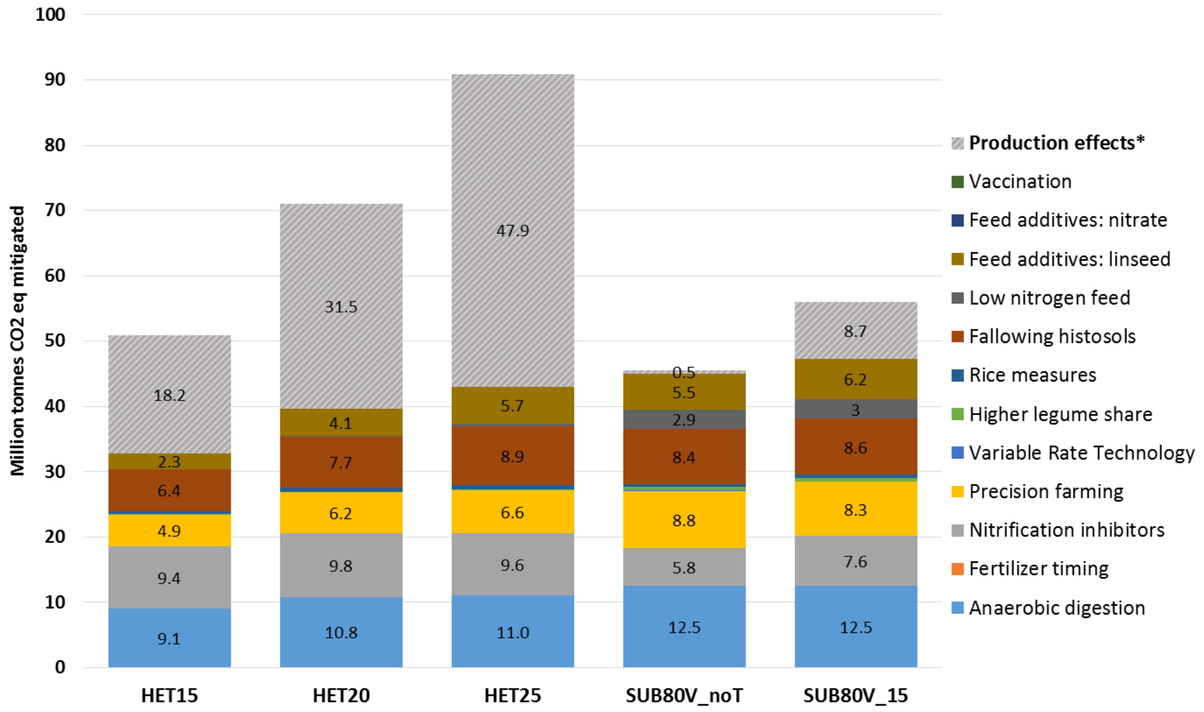
Note: na = technology not available in the scenario. If an implementation share of 0 % is indicated, shares are below 0.5 % at the aggregated EU-28 level.

Figure 30 presents the absolute and Figure 31 and Figure 32 present the relative contribution of each technological mitigation option to total mitigation. In the HET scenarios, the contribution of each mitigation technology to total mitigation decreases with the increase in the mitigation target, which is not surprising given the increasing level of mitigation that has to be achieved via production changes (see also Table 29). As mentioned above, depending on the mitigation technology, this is because either the maximum level of implementation or the cost-effective implementation level of the technologies is reached. In terms of absolute contribution to emission reduction (Figure 30), the total reduction achieved with mitigation technologies increases from 32.8 million tonnes of CO_2 equivalents in HET15 to 39.6 million tonnes of CO_2 equivalents in HET20 and 43 million tonnes of CO_2 equivalents in HET25. Moreover, if no mitigation target is set but the mitigation technologies are subsidised (SUB80V_noT), mitigation technologies achieve a reduction of 45.1 million tonnes of CO_2 equivalents, whereas in the SUB80V_15 scenario the total reduction achieved with mitigation technologies reaches 47.3 million tonnes of CO_2 equivalents.

In the HET scenarios, anaerobic digestion contributes most to mitigation, followed by nitrification inhibitors, fallowing histosols, precision farming and linseed as a feed additive. The same rank order is basically also seen in the SUB80V_noT scenario, with the exception that the contribution of precision farming increases considerably, reaching 8.8 million tonnes of CO_2 equivalents compared with, for example, 4.9 million tonnes of CO_2 equivalents in the HET15 scenario. This increase is at the expense of the application of nitrification inhibitors, with the contribution to mitigation of this measure decreasing to 5.8 million tonnes of CO_2 equivalents (compared with 9.4 million tonnes of CO_2 equivalents in HET15). Moreover, SUB80V_noT also shows a considerable uptake of low nitrogen feed, contributing to mitigation about 2.9 million tonnes of CO_2 equivalents (compared with 0.06 million tonnes of CO_2 equivalents in HET15).

Regarding the difference between the HET15 and SUB80V_15 scenarios, application generally increases for all technologies when subsidies are paid for their implementation. As in the SUB80V_noT scenario, the exception is nitrification inhibitors, which are applied less, particularly because of the increase in precision farming (with the latter's contribution to emission reduction increasing to 8.3 million tonnes of CO_2 equivalents in SUB80V_15). Again, low nitrogen feed also shows a considerable uptake in SUB80V_15, and contributes 3 million tonnes of CO_2 equivalents to mitigation.

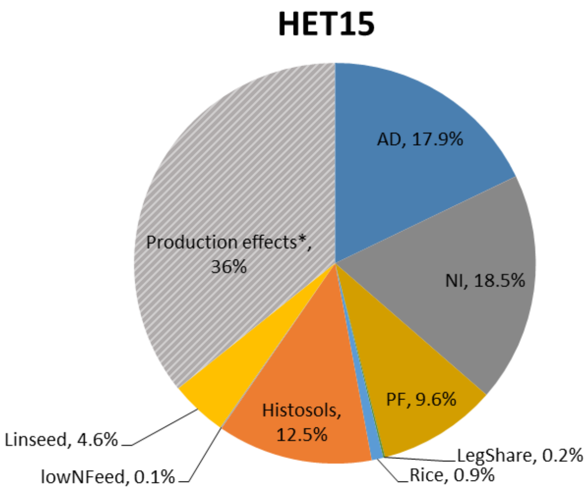
Figure 30: Contribution of each technological mitigation option to total mitigation in the EU-28 (complementary scenarios)

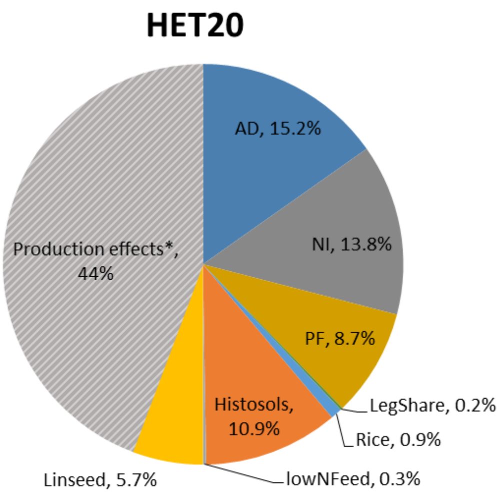


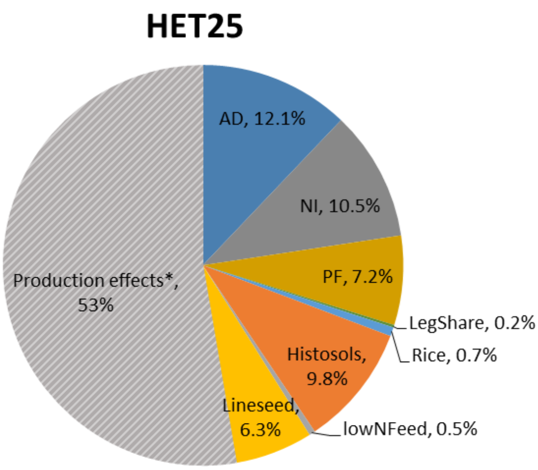
* The mitigation effects linked to genetic improvement measures cannot be analysed in isolation and are included in the mitigation achieved by changes in production.

To get a better idea of the efficiency of the use of subsidies for the application to technological mitigation options in the scenarios SUB80V_noT and SUB80V_15, the contribution of each option to total mitigation (see Figure 30 to Figure 32) has to be compared with the share of this option in the total subsidies paid for mitigation technologies (Figure 33). However, as noted in the section 6.1.6 on the main scenarios, there are limitations to the comparability of mitigation costs per technology and these figures should be considered with caution.

Figure 31: Relative contribution of each technological mitigation option to total mitigation (HET scenarios)



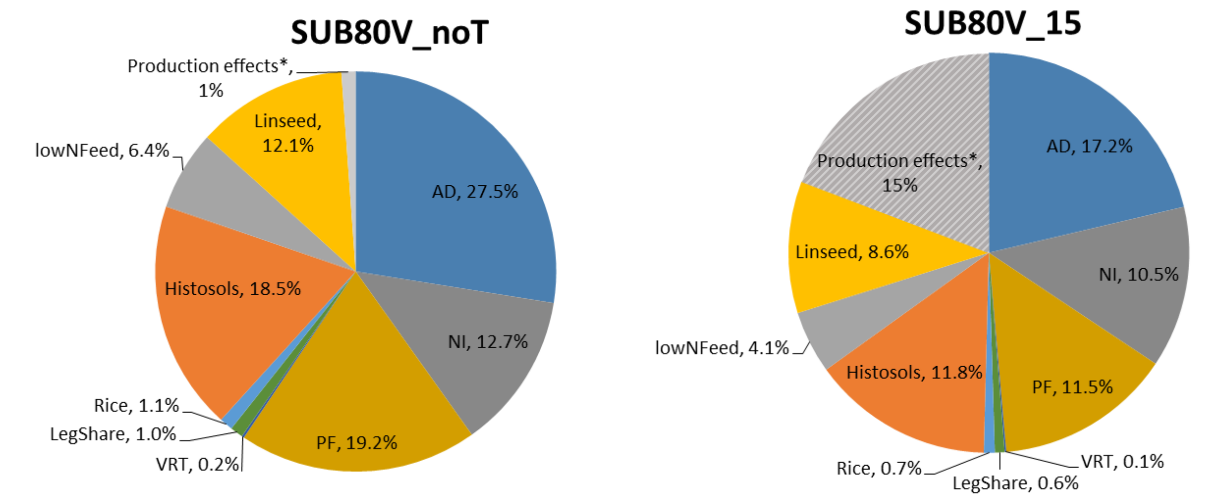




Note: AD = anaerobic digestion; NI = nitrification inhibitors; PF = precision farming; VRT = Variable Rate Technology.

* The mitigation effects linked to genetic improvement measures cannot be analysed in isolation and are included in the mitigation achieved by changes in production (see Box 2).

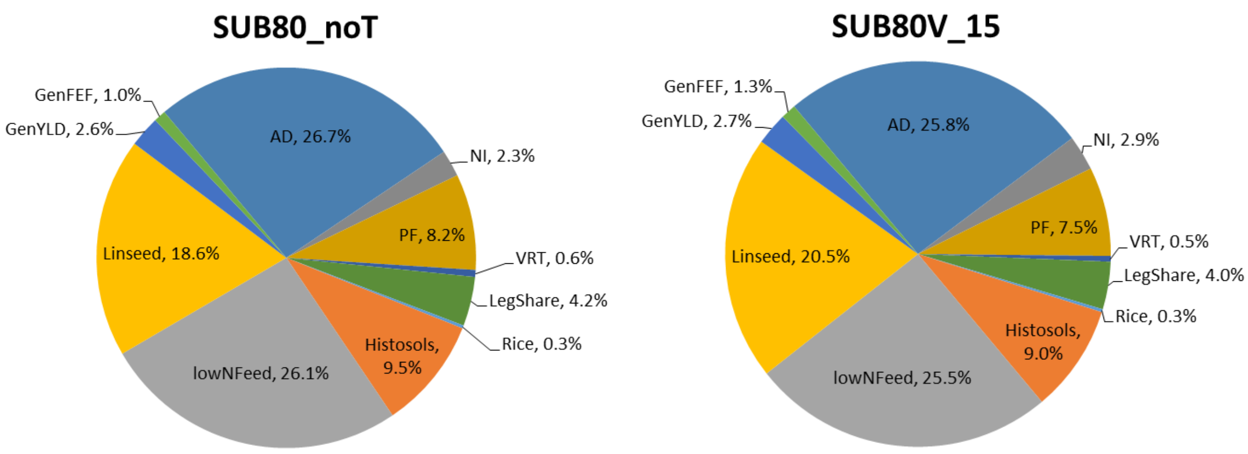
Figure 32: Relative contribution of each technological mitigation option to total mitigation (SUB80V_noT and SUB80V_15 scenarios)



Note: AD = anaerobic digestion; NI = nitrification inhibitors; PF = precision farming; VRT = Variable Rate Technology.

* The mitigation effects linked to genetic improvement measures cannot be analysed in isolation and are included in the mitigation achieved by changes in production (see Box 2).

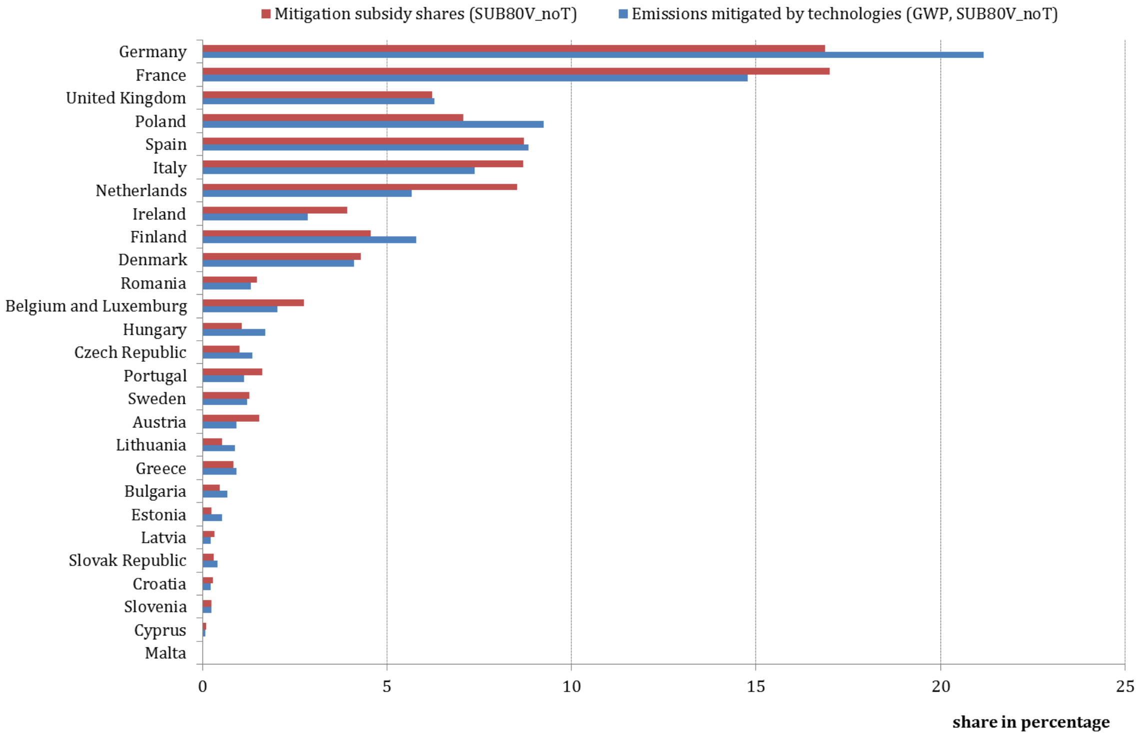
Figure 33: Share of technology options in total mitigation subsidies in the EU-28 (SUB80V_noT and SUB80V_15 scenarios)

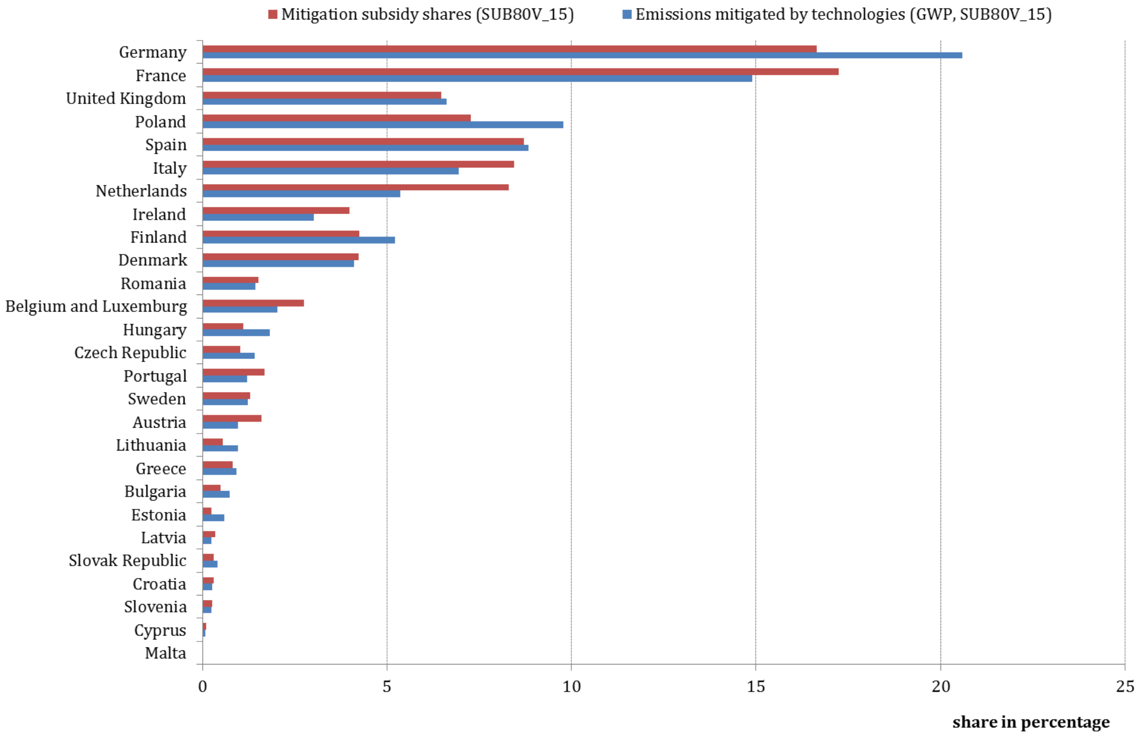


Note: AD = anaerobic Digestion; NI = nitrification inhibitors; PF = precision farming; VRT = Variable Rate Technology.

Figure 34 presents each Member State's share in total EU-28 subsidies for mitigation technologies and share in total mitigation via technology adoption in the scenarios SUB80V_noT and SUB80V_15. The most important points highlighted by this figure are the same as those indicated in the main scenarios: the distribution of mitigation and the distribution of emissions are highly correlated, with greater mitigation occurring in Member States with higher total emissions. This pattern is less prominent when one focuses on the mitigation achieved via technology implementation, showing that, in some Member States, there is more mitigation via production shifts. Furthermore, the mix of technologies adopted for mitigation in some countries (e.g. Germany, Poland) is cheaper than in others (e.g. France, the Netherlands, Italy).

Figure 34: Member States' share in total subsidies of mitigation technologies and contribution to total mitigation via technology adoption (SUB80V_noT and SUB80V_15 scenarios)





Note: The bar 'Emission mitigated by technology' does not include the mitigation effects from the measures related to genetic improvements, as it is not possible to disentangle the effects of the breeding programmes on total agricultural emissions from their related production effects (see Box 2).

6.2.6 Impact on the EU budget and economic welfare

From a budgetary point of view, the setting of mitigation targets without paying subsidies for the application of mitigation technologies (HET15/HET20/HET25) has no additional cost for the EU budget (Table 31). However, as shown in previous sections, impacts on production and emission leakage can be significant. By contrast, paying subsidies for the uptake of mitigation technologies without setting mitigation targets (SUB80V_noT) helps avoid the negative impacts on EU agricultural production and also on emission leakage, but comes with substantial budgetary costs of EUR 12.7 billion. Setting a mitigation target and simultaneously subsidising the uptake of mitigation technologies (SUB80V_15) helps to reduce negative impacts on EU agricultural production and emission leakage, but again comes with substantial budgetary costs (EUR 13 billion). It has to be noted that the usual disclaimer used throughout the report regarding the modelling approach on costs etc. also applies here (see section 6.1.6).

Table 31: Total subsidies for mitigation technologies in the EU-28, 2030 (complementary scenarios)

Scenario		Total subsidies to mitigation technologies (Billon Euro)	Subsidy per tonne total CO_2eq mitigated (Euro/t)
Non-subsidised Voluntary Adoption of Technologies	HET15/HET20/ HET25	NA	NA
Subsidised Voluntary Adoption of Technologies, No Mitigation Target	SUB80V_noT	12.7	278
Subsidised Voluntary Adoption of Technologies	SUB80V_15	13.0	233

Note: The subsidies presented are for the projection year 2030, are relative to the REF scenarios and are in prices of 2030.

From a sectoral perspective, economic welfare (i.e. only considering welfare linked to agricultural marketed outputs and not to, for example, environmental externalities) is indicated to rise with increasing mitigation targets (Table 32). This positive effect is the result of increasing agricultural income and industry profits owing to the higher prices for agricultural products, which over-compensate for the loss in consumer surplus. Agricultural income is indicated to increase by about 5 % in HET15, 10% in HET20, and 18% in HET25. Regarding the increase in EU-28 agricultural income, as indicated in the text to the main scenarios (section 6.1.6), it has to be noted that agricultural income effects can vary considerably between both regions and agricultural sectors, and the model used does not provide results on the number of farmers/farms that will remain active and benefitting from the potential increases in total agricultural income (i.e. the model does not consider farm-level structural change).

In contrast to the HET scenarios, total welfare decreases in the scenarios with subsidies paid for the uptake of technological mitigation options. Agricultural income is indicated to increase by 4% in the SUB80V_15 scenario and by merely 1% in the SUB80V_noT scenario. In the SUB80V_noT scenario, the increases in agricultural income (owing to the subsidies for the uptake of technologies) and consumer surplus (owing to decreases in consumer prices) do not compensate for the budgetary burden of subsidising the mitigation technologies. In the SUB80V_15 scenario, adverse production effects are diminished by the subsidies for mitigation technologies, which leads to a lower increase in agricultural prices than in HET15. As a consequence, the decrease in consumer surplus and the increase in agricultural income are less than in HET15, but the net effect is still a EUR 9.3 billion decrease in total welfare as a result of the subsidies paid by the taxpayer (Table 32).

Table 32: Decomposition of welfare effects in the EU agricultural sector, 2030 (complementary scenarios)

	HET15	HET20	HET25	SUB80V _noT	SUB80V _15
	Billion EUR (absolute difference to REF)				
Total welfare [1]	2.0	6.0	10.4	-11.8	-9.3
Consumer surplus [2]	-11.0	-21.0	-35.1	3.9	-0.4
Agricultural income	10.3	21.7	37.5	2.6	8.6
…of which are subsidies for mitigation technologies	0.0	0.0	0.0	12.7	13.0

[1] Welfare effects linked to the European agricultural sector, calculated as the sum of consumer surplus plus producer surplus (agricultural income and profits from the processing industry) plus tariff revenues minus taxpayer costs. Additional effects on other sectors, for example induced by changes in consumer surplus or taxpayer costs, are not covered in this modelling approach.

[2] For consumers, CAPRI uses the money metric concept to measure consumer welfare. It can be broadly understood as a measurement of changes in the purchasing power of the consumer.

As explained in the text to the main scenarios (section 6.1.6), it is important to note that we are computing welfare effects from only a partial equilibrium (sectoral) perspective, namely welfare effects linked to the European agricultural sector. Thus, possible additional effects on other sectors, for example induced by changes in consumer surplus or taxpayer costs, are not covered in the modelling approach.

7 Conclusions and further research

In the context of possible reductions of non-CO_2 emissions from EU agriculture, the scenario results of the EcAMPA 2 study highlight issues related to production effects, the importance of technological mitigation options and the need to consider emission leakage for an effective reduction of global agricultural GHG emissions. More specifically, scenario results reveal the following four major points:

(1) Without further (policy) action, agricultural GHG emissions in the EU-28 are projected to decrease by 2.3% by 2030 compared to 2005.

(2) In our simulation scenarios, the setting of GHG emission reduction obligations for the EU agriculture sector without financial support shows important production effects, especially in the EU livestock sector.

(3) The decreases in domestic production are partially offset by production increases in other parts of the world, what could considerably diminish the net effect of EU mitigation efforts on global GHG emissions.

(4) Adverse effects on EU agricultural production and emission leakage are significantly reduced if subsidies are paid for the application of technological emission mitigation options. However, this comes along with considerable budgetary costs, as farmers are projected to widely adopt the technologies.

The results of this study have to be considered as indicative and contemplated within the specific framework of assumptions of the study. Follow-up work is planned to focus on the improvement of the modelling framework. The current methodology needs further refinements, especially regarding the representation of mitigation technologies and possible related subsidies. Therefore further research is particularly needed with respect to costs, benefits and uptake barriers of technological mitigation measures. Furthermore, agricultural carbon dioxide emissions have to be incorporated into the analysis. Moreover, further improvements regarding the estimation of emission leakage effects are required. Likewise it is necessary to closely observe how the global climate agreement reached at the COP21 in Paris will be put into action. Therefore, future studies have to consider how other parties integrate the agricultural sector into their Intended Nationally Determined Contributions under the Paris Agreement. In addition, for follow-up studies the emission factors used for calculation and reporting should be aligned to the Global Warming Potentials used in the latest Assessment Reports of the IPCC.

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ANNEXES

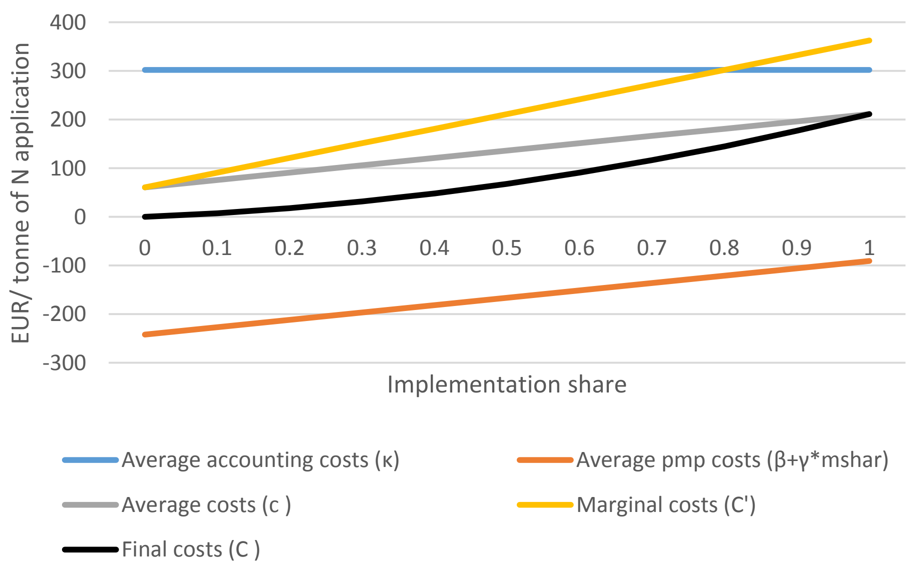
Annex 1: How are technological emission abatement costs depicted in CAPRI? A numerical example for precision farming in Denmark

The original data from GAINS (2015) for precision farming as a mitigation technology suggests average accounting costs of EUR 302/tonne nitrogen applied, achieving a 36 % reduction of mineral fertiliser application (see blue line in Figure 35). Annual nitrogen application in Denmark is, according to CAPRI, projected to be 161 000 tonnes per year in 2030. Therefore, a simple cost estimation for a 100 % implementation rate would give an estimation of EUR 48.6 million (161 000 tonnes * EUR 302).

In order to guarantee increasing marginal costs, a quadratic average cost function was derived. It is important to note that this function relates to the implementation shares (i.e. x-axis in Figure 35) and not to nitrogen application rates. Therefore, at each implementation share you get average costs that have to be multiplied by the nitrogen application and the implementation share in order to achieve total costs, which leads to an upwards sloping linear marginal cost function. This functional form and the calibration method are described in Chapter 4.

Average accounting costs are assumed to be positive, while the implementation level in the base year is considered zero. Therefore, the calibration tool would assume that a full implementation share (100 %) could be achieved with a 120 % subsidy of the average accounting costs (EUR 362/tonne), while the first 'early adopters' would start using the technology with a subsidy of 20 % of the average accounting costs (EUR 60/tonne). The resulting values for β and γ are −241.8 and 302, respectively. The corresponding cost functions (depending on the implementation share) are shown in Figure 35.

Figure 35: Example of the costs of precision farming in Denmark



The blue line shows the constant average accounting costs (κ) reported in the GAINS database. The orange line shows the average pmp costs ($\beta + 0.5 * \gamma * mshar$), which, being negative, represent unreported gains to farmers from implementation of the technology. The grey line, the total average costs (corresponding to c^m), is the sum of the blue and the orange line and the black line is the final cost curve (C^m), whereas the yellow line shows the marginal costs ($\kappa + \beta + \gamma * mshar$). Marginal costs are exactly 20 % of the average net accounting costs (EUR 60.4) at a zero implementation share, and 120 % (EUR 362.6) at an implementation share of 100 %.

Now we will consider the introduction of a subsidy of 80 % of the average net accounting costs (EUR 241.6/tonne nitrogen applied) for the implementation of precision farming (and not to any other measure). As long as the marginal costs stay below this value, the region will move towards the right, increasing the implementation share, ending up at a value slightly below 60 % (marginal costs at 60 % are EUR 241.8/tonne nitrogen applied). Total costs for subsidies would be around EUR 23.34 million (0.6 * 161 000 * 241.6), total accounting costs for the farmers (not considering the subsidies) would be EUR 29.17 million (0.6 * 161 000 * 302) and the total costs (including the pmp costs) would be EUR 14.6 million (0.6 * 161 000 * 151). This also shows that, by taking only the accounting costs and subsidies into account, farmers would suffer a loss of around EUR 5.8 million, whereas also considering the pmp costs farmers would end up with a net gain of about EUR 8.8 million.

What is the effect of the assumption regarding the relative subsidy needed for adoption of a technology? In the above example, we assume that the first 'early adopters' will start implementing the technology if a subsidy of 20 % of the average accounting costs is paid, while a 100 % implementation rate is achieved with a subsidy rate of 120 %. If we change these assumptions, we would logically achieve different implementation rates. For instance:

- If we were to change the parameter for 'late adopters' from 120 % to 150 %, an 80 % subsidy would imply a lower implementation rate of 46 %. In contrast, if we were to change this parameter to 100 % and 80 %, implementation rates would increase to 75 % and 100 %, respectively.
- If we were to change the parameter for 'early adopters' from 20 % to 10 %, we would end up with an implementation rate of 55 %. By contrast, marginal and average costs (EUR 241.6 and EUR 151) for a given subsidy at the optimal implementation rate would not be affected by the change of the calibration parameters. Total costs would change proportionally to the implementation.

Unfortunately, most of the technologies are more complicated than the simple show case example presented. On the one hand, this is the result of endogenous variables influenced by the use of the technology (especially feed and fertiliser use, but also yields, etc.). On the other hand, it is due to the parallel use of various technologies, from which many cannot be combined without interaction. Moreover, other limitations might prevent a cost-effective solution. Therefore, each of the technologies has its particularities in the calibration, which sometimes makes it difficult to ensure consistency and comparability. With respect to this, further work on the calibration methodology might be undertaken.

Annex 2: Restriction of fertiliser measures in the scenarios with standard assumptions on technological development

The reduction effects of fertiliser technologies are based on information from the GAINS database (2015). However, based on information from fertiliser sales, animal production, crude protein content of plants, yields, etc., CAPRI estimates endogenous 'business-as-usual' over-fertilisation factors (i.e. nitrogen availability divided by nitrogen need) at the regional level. Thus, by simply applying the reduction factors of mitigation technologies from GAINS, we could end up with an availability of nitrogen below the actual plant need.

To avoid this, an upper limit for the reduction effect of all measures is applied. This upper limit corresponds to the 'business-as-usual' over-fertilisation factor plus 10 %. However, by applying only the upper limit, cheaper fertiliser reduction measures could be selected, which could pose a problem, as a low over-fertilisation factor indicates an already efficient fertilisation strategy, implying that further reduction might be possible only with more sophisticated, usually more expensive, technologies. Therefore, cheaper technologies are increasingly restricted for lower over-fertilisation factors.

We start from the assumption that, with a 100 % application share of precision farming (i.e. the most efficient technology), we cannot achieve more reduction than the business-as-usual over-fertilisation plus 10 % or, in other words, we cannot go below the nitrogen need minus 10 %. For regions where the level of nitrogen fertilisation with the full application of precision farming remains above this value (i.e. nitrogen need minus 10 %), we do not need to change anything. In contrast, if it is below, we reduce the maximum implementation share for all mitigation technologies. The basic idea is that we have to reduce the potential of all measures by the difference between the theoretical reduction potential of precision farming and the actual reduction potential defined based on the nitrogen need.

Following this method, we assume that, on average, a farmer will first apply cheap measures and then the more expensive ones. If the potential of precision farming is lower than in theory, this is because equivalent measures to the cheap technologies have already been implemented (e.g. VRT) and are, therefore, no longer available. Therefore, we redefine the maximum implementation share of a technology, *msh(tech)* (i.e. the maximum proportion of the total nitrogen from mineral fertilisers in the region to which the technology is applicable), in the following way:

$$\mathrm{msh}'(tech) = \frac{n(noc) - min[n(noc), (n(tech) + n(need) * 0.9 - n(pf))]}{n(noc) - n(tech)}$$

where $n(noc)$ is the fertiliser application in the reference scenario (business as usual); $n(tech)$ is the fertiliser application with the technology, *tech*, according to information from GAINS; $n(need)$ is the fertiliser need; and $n(pf)$ is the fertiliser application when precision farming is applied.

Assuming that $n(noc)$ = 140 tonnes, $n(pf)$ = 100 tonnes, $n(need)$ = 120 tonnes and $n(tech)$ = 135 tonnes, we would add the difference between $n(need)$ * 0.9 and $n(pf)$ (108 – 100 = 8 tonnes) to $n(tech)$, which gives 143. As 143 is higher than $n(noc)$, we reduce this to the maximum value of $n(noc)$ (140 tonnes). In total, we get a maximum implementation share, *msh'*(*tech*), of zero ((140 – 140)/(140 – 135) = 0), because we assume that the relatively small reduction potential of the technology has already been achieved via other equivalent measures. By contrast, assuming that $n(tech)$ = 115 tonnes, we end up with a value of 123 tonnes and, as a consequence, with a maximum implementation share, *msh'*(*tech*), of 17/25. So, only 8/25 of the potential has already been achieved in the baseline via equivalent measures. Obviously, precision farming would end up with a maximum implementation rate of 80 %, which guarantees that the value of $n(pf)$ will be equivalent to $n(need)$ * 0.9.

Annex 3: Sensitivity analysis (I): The impact of different assumptions on relative subsidies for technology adoption

In the calibration approach underlying all mitigation scenarios described in this report, an assumption is taken about the value of subsidies needed to achieve a full adoption of a mitigation technology ('full implementation subsidies'). In order to analyse how these assumptions might influence the actual adoption of a technology in the scenarios, we carried out a sensitivity analysis by taking the SUB80V_TD scenario and changing the full implementation subsidies in the calibration to 75 % (SA75) or 150 % (SA150) of their standard values for the most frequent case.[35] The relative subsidy changes in the following ways:

- SA75 scenario: we assume that a technology is already fully adopted when 120 % * 75 % = 90 % of the cost is subsidised (i.e. this is a less stringent scenario regarding technology adoption). This assumes that farmers adopt new technologies easily, for example because they have preferences towards climate-friendly management or towards new technologies in general or because our cost assumptions have been slightly too pessimistic.
- SA150 scenario: we assume that a technology is fully adopted when 120 % * 150 % = 180 % of the cost is subsidised (i.e. this is a more stringent scenario regarding technology adoption). This assumes a greater resistance towards the adoption of mitigation technologies, for example because some farmers are more conservative regarding new technologies or because our cost assumptions have been too optimistic compared with 'real-world circumstances'.

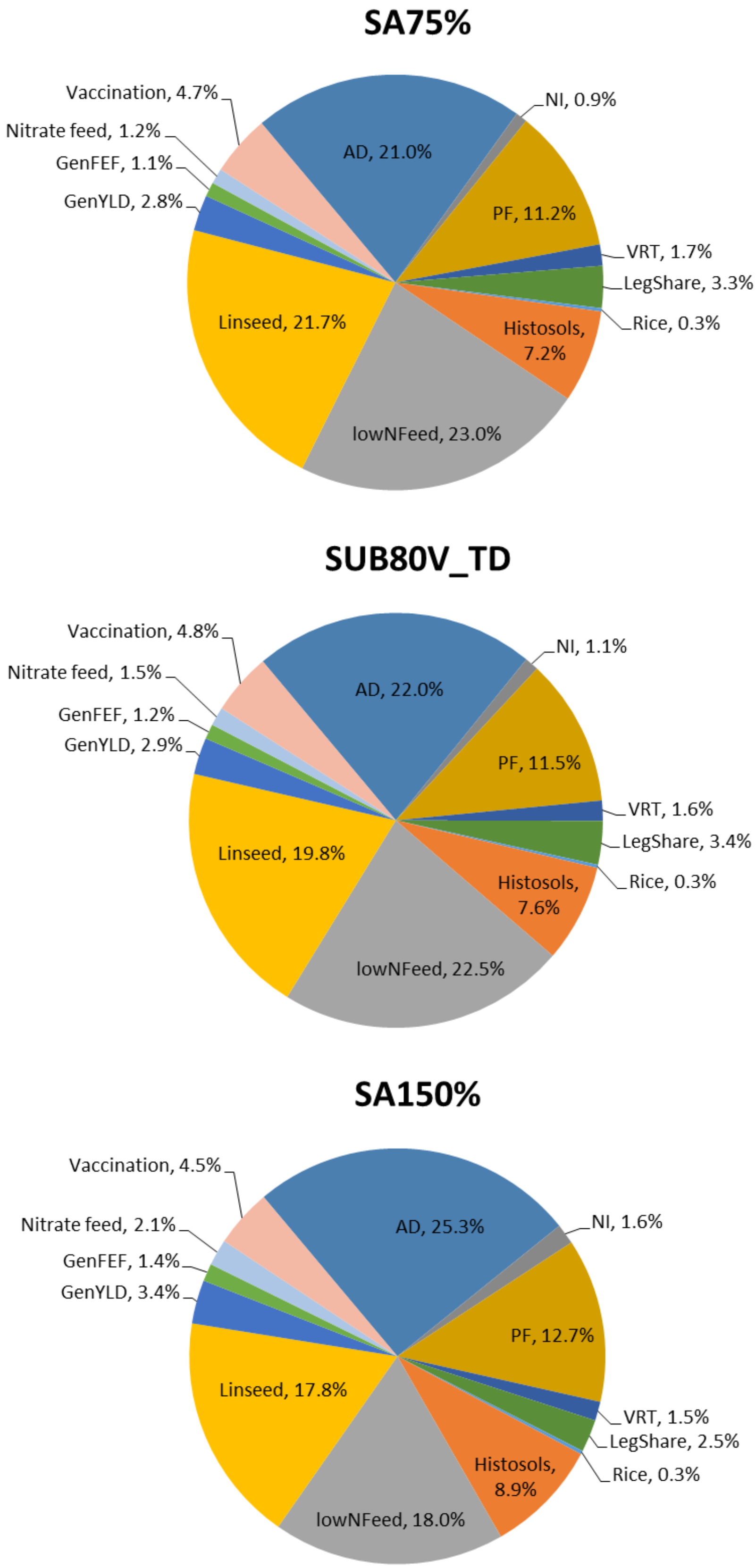
In very general terms, technology adoption is facilitated under SA75 and impeded under SA150. However, results of this sensitivity analysis show that the implementation share for single technologies does not dramatically change with a changing relative subsidy assumption. Naturally, as adoption is cheaper, implementation shares are generally higher in the SA75 scenario. For single mitigation technologies, Table 33 shows that there is some sensitivity of the implementation rates to the relative subsidies, with the sensitivity being larger if the implementation shares are basically unconstrained and do not compete with similar measures (e.g. milk yields) than if there are other constraints and measures competing with each other (e.g. fertiliser measures and measures related to enteric fermentation). In the case of anaerobic digestion, the subsidy assumption plays only a supplementary role in the specification under EcAMPA 2 and, therefore, no (visible) changes are observed for this measure. If some mitigation measures are modelled as alternative options that cannot be applied on top of each other (such as fertiliser measures or vaccination and feed additives), then decreasing adoption of more expensive measures (such as precision farming or vaccination) may accompany increased use of cheaper but less effective measures (such as nitrification inhibitors or nitrates). Furthermore, some measures may increase (such as breeding for feed efficiency or protection of histosols) because other measures have been adopted to a lower extent.

[35] Most frequent case: cost > 0, revenue = 0, reference run implementation rate = 0 %.

Table 33: Implementation and maximum possible shares of technologies at the EU level according to the sensitivity analysis (% of agricultural area or herd sizes)

Technology	Implementation share			Maximum possible share		
	SA75%	SUB80V_TD	SA150%	SA75%	SUB80V_TD	SA150%
Anaerobic digestion	33%	33%	33%	33%	33%	33%
Better fertilization timing	0%	0%	0%	100%	100%	100%
Nitrification inhibitors	18%	21%	27%	60%	60%	60%
Precision farming	65%	64%	61%	100%	100%	100%
Variable Rate Technology	16%	14%	12%	100%	100%	1000%
Higher legume share	80%	80%	52%	100%	100%	100%
Rice measures	93%	85%	81%	100%	100%	100%
Fallowing histosols	79%	80%	81%	100%	100%	100%
Low nitrogen feed	38%	35%	26%	55%	55%	56%
Feed additives: linseed	25%	21%	17%	28%	28%	28%
Increasing milk yields of dairy cows	49%	50%	50%	100%	100%	100%
Increasing ruminant feed efficiency	69%	70%	72%	100%	100%	100%
Feed additives: nitrate	10%	11%	14%	44%	44%	44%
Vaccination (methanogenic bacteria in the rumen)	74%	73%	62%	100%	100%	100%

Figure 36: Share of each technological mitigation option in total mitigation subsidies in the EU-28 (sensitivity analysis I)



Note: AD = anaerobic digestion; NI = nitrification inhibitors; PF = precision farming; VRT = Variable Rate Technology.

With regard to total emissions, the results are not sensitive to the assumption of the 'full implementation subsidies' of mitigation technologies, as, by design, the emission reduction target has to be met in these scenarios. Thus, the general effect is that an increase in the assumed 'full implementation subsidy' tends to reduce the adoption of mitigation technologies and production has to be adjusted more to achieve the targeted emission reduction. The effects on agricultural production are most pronounced for animal activities (i.e. we see that the effect on agricultural activity levels decreases more (or increases less) when moving from SA75 to SA150). However, Table 34 shows that the sensitivity of the aggregated EU-28 agricultural activity levels to the relative subsidy assumed in the calibration process is, in general, rather low.

Table 34: Changes in agricultural activity levels according to the sensitivity analysis in the EU-28

	REF	SA75%	SUB80V_TD	SA150%
	1000 heads or ha	%-change compared to REF		
UAA	180898	-1.4%	-1.4%	-1.6%
Cereals	57271	-1.6%	-1.8%	-2.1%
Oilseeds	12040	-1.4%	-1.5%	-1.5%
Soft wheat	23621	-1.4%	-1.5%	-1.8%
Grain Maize	10117	-2.7%	-2.9%	-3.3%
Rape	6681	-1.8%	-1.9%	-2.0%
Sunflower	4588	-0.7%	-0.7%	-0.7%
Fodder activities	82230	-4.8%	-4.9%	-5.2%
Grass and grazings extensive	29244	-1.3%	-1.2%	-1.0%
Grass and grazings intensive	29176	-8.8%	-9.0%	-9.5%
Fallow land	4483	6.8%	7.3%	8.4%
All cattle activities	58371	-3.7%	-4.1%	-5.0%
Dairy Cows high yield	10759	-2.4%	-2.4%	-2.7%
Other Cows	12274	-7.1%	-8.2%	-10.5%
Male adult cattle high weight	4350	-2.8%	-3.1%	-3.7%
Beef meat activities	17985	-5.3%	-6.1%	-7.7%
Pig fattening	233781	0.8%	0.6%	-0.1%
Poultry fattening	6882	1.2%	0.9%	0.3%
Arable land	122478	0.4%	0.3%	0.1%

Annex 4: Sensitivity analysis (II): The impact of different carbon prices on the distribution of mitigation efforts

One of the key requirements for the scenario results being useful for policy analysis is that they are robust, in the sense that they do not vary too much when changing key assumptions. In EcAMPA 2, the distribution of the EU-wide 20 % mitigation target among Member States reflects the results of running a scenario (Carb50) that imposes a carbon price of EUR 50/tonne CO_2 equivalents (i.e. including CH_4 and N_2O emissions in EU agriculture as calculated by the model). Under this scenario, the overall mitigation achieved is 9.9 % compared with 2005, with emission efforts heterogeneously distributed among the Member States. To make sure that the 20 % mitigation target is achieved in the main scenarios, a linear shifter is applied to the emissions efforts of all Member States. It may be argued that the introduction of this linear shifter does not lead to a cost-efficient allocation of efforts for the 20 % target. To test this, we ran 11 scenarios with different carbon prices, ranging from EUR 10 to 500/tonne CO_2 equivalents (Carb10 to Carb500).

For each of the carbon price scenarios, the model allocates mitigation impacts differently across Member States, as depicted in Table 35. Two tests were conducted to see whether or not there were significant differences in the allocation between the scenarios. First, we compared the ranking of efforts between the EU-15 and the EU-N13, as shown in Figure 37. As can be seen, the ranking does not change in terms of either relative effort (Figure 37(a)) or absolute emissions (Figure 37(b)). Nevertheless, the ratio of mitigation between the two regions increases with higher carbon prices. This shows that, with low carbon prices, cheap mitigation is more abundant in the EU-N13, as the logic behind CAPRI reduces production in regions with lower profits first. However, as soon as the carbon price hits EUR 50, the mitigation potential is similar in both regional aggregates, as the option of reducing low profit production in the EU-N13 has already been exhausted.

Furthermore, using mitigation efforts at the Member State level, we tested whether the changes depicted in Table 35 were statistically significant or not. To do this, we conducted two statistical tests comparing the ranking of efforts by Member State by scenario. The Friedman test shows that equality of ranking cannot be ruled out, meaning that the ranking of mitigation efforts between Member States is actually not really affected by scenarios with different carbon prices. The equivalent Kendall's Coefficient of Concordance (KCC) gives the same results.[36] Therefore, we conclude that the assumption of the cost-effective distribution of mitigation efforts among Member States implemented in EcAMPA 2, based on the results of a carbon price of EUR 50/tonne CO_2 equivalents, does not have a significant impact on the results.

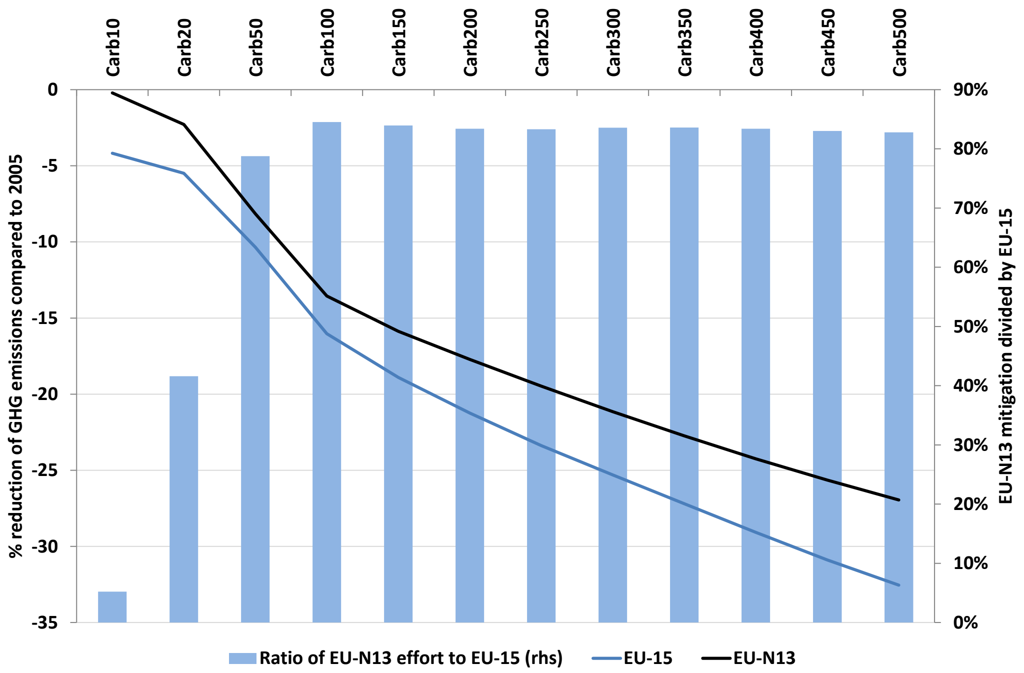
While the testing approach is a natural response to acknowledging the multiple uncertainties related to modelling, it does not totally rule out the fact that the allocation of efforts among Member States based on the Carb50 scenario plus a linear shifter is different to that of the Carb200 scenario, which approximately reflects the efficient allocation of mitigation efforts across Member States for a 20 % EU-28 mitigation effort. Comparing the results for the main indicators considered in the report (i.e. changes in GHG emissions, activity level aggregates and implementation of individual technologies),

[36] The null hypothesis of the Friedman non-parametric test is that the treatments across multiple test attempts are equal (i.e. that the scenarios have no impact on the ranking of mitigation efforts). The Friedman statistic takes a value of 282.21 with an associated probability of 0.000, which does not allow rejection of the null hypothesis. The equivalent KCC takes a value of 0.9045 and is easier to interpret, as the closer the KCC is to 1, the closer the agreement of rankings between scenarios.

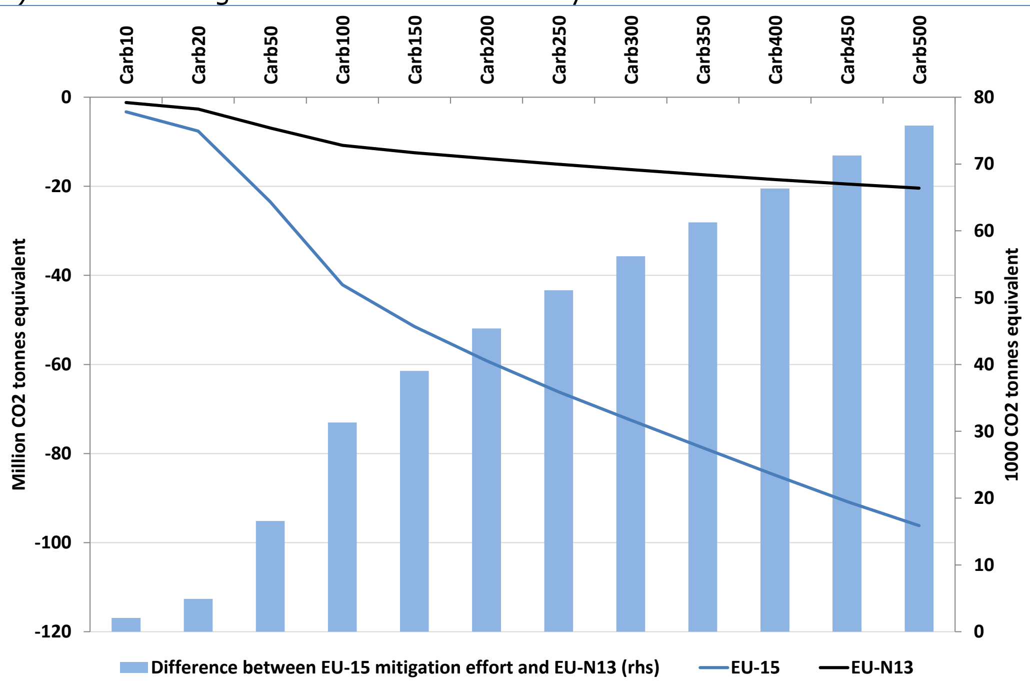
one can conclude that, while not identical,[37] patterns are sufficiently similar, and HET20 can also be considered efficient.

Figure 37: Relative and absolute mitigation of GHG emissions by scenario for the EU-15 and the EU-N13

(a) Relative mitigation of GHG emissions by scenario for the EU-15 and the EU-N13



(b) Absolute mitigation of GHG emissions by scenario for the EU-15 and the EU-N13



[37] With regard to GHG savings, Finland and Ireland have lower GHG reductions in HET20 than in Carb200, while, for Austria and Slovakia, the contrary is true. As far as activity levels are concerned, the HET20 scenario has significantly lower set aside than Carb200, which relates to the adoption of fallowing histosols.

Table 35: Mitigation efforts per Member State for the different carbon price scenarios

	Carb											
	10	20	50	100	150	200	250	300	350	400	450	500
European Union	-3.5	-4.9	-9.9	-15.6	-18.4	-20.6	-22.7	-24.6	-26.4	-28.2	-29.9	-31.5
Austria	0.4	-0.4	-3.3	-6.6	-8.4	-10.0	-11.4	-12.8	-14.1	-15.4	-16.7	-17.8
Belgium	-13.5	-14.9	-19.8	-25.2	-27.4	-28.9	-30.4	-31.8	-33.2	-34.7	-36.1	-37.6
Denmark	-1.8	-3.5	-9.0	-14.9	-16.8	-18.3	-19.7	-21.0	-22.2	-23.3	-24.4	-25.3
Finland	0.0	-4.2	-14.1	-26.2	-32.9	-43.2	-51.8	-52.7	-53.7	-54.6	-55.5	-56.2
France	-4.9	-6.0	-10.4	-15.9	-18.7	-20.5	-22.0	-23.4	-24.7	-26.1	-27.3	-28.5
Germany	-3.8	-5.7	-12.2	-18.4	-20.8	-22.8	-24.2	-25.4	-26.6	-27.8	-28.9	-30.0
Greece	-2.9	-3.7	-7.0	-11.0	-13.1	-14.5	-15.8	-17.1	-18.4	-19.7	-21.0	-22.4
Ireland	1.7	0.8	-3.0	-8.4	-12.5	-16.5	-20.8	-25.3	-29.8	-34.2	-38.2	-41.1
Italy	-16.5	-17.1	-21.1	-26.8	-29.7	-30.9	-32.0	-33.0	-34.1	-35.1	-36.0	-36.8
Netherlands	-2.4	-3.5	-7.4	-12.4	-15.2	-17.8	-20.3	-22.7	-24.8	-26.7	-28.6	-30.1
Portugal	8.0	6.3	1.2	-4.3	-7.9	-11.2	-14.3	-17.3	-20.2	-22.9	-25.5	-27.9
Spain	10.6	9.1	3.8	-2.4	-5.1	-7.2	-9.1	-11.0	-12.9	-14.8	-16.6	-18.4
Sweden	-2.0	-3.0	-6.7	-11.2	-13.8	-15.8	-17.8	-19.7	-21.5	-23.3	-24.9	-26.4
United Kingdom	-10.7	-11.8	-15.7	-20.8	-23.8	-26.7	-29.8	-33.0	-36.3	-39.9	-43.4	-46.8
EU-15	-4.2	-5.5	-10.3	-16.0	-18.9	-21.2	-23.4	-25.3	-27.2	-29.1	-30.9	-32.5
Bulgaria	4.1	3.7	0.1	-5.7	-7.5	-9.2	-11.0	-12.7	-14.4	-16.0	-17.6	-19.1
Croatia	-5.0	-5.6	-8.4	-13.3	-17.7	-20.6	-22.6	-24.5	-26.4	-28.3	-30.2	-31.9
Cyprus	13.1	11.9	7.8	2.7	0.4	-1.4	-3.2	-5.0	-6.8	-8.5	-10.3	-12.0
Czech Republic	-0.9	-2.4	-8.2	-14.9	-17.8	-20.0	-22.2	-24.3	-26.2	-28.0	-29.4	-30.7
Estonia	23.1	17.3	12.2	5.8	1.6	-2.0	-5.2	-8.3	-11.3	-14.2	-16.7	-18.3
Hungary	-0.2	-2.6	-8.3	-13.4	-15.5	-16.8	-18.0	-19.1	-20.2	-21.3	-22.3	-23.2
Latvia	20.7	19.7	16.5	12.0	8.7	5.8	2.8	-0.1	-3.0	-5.8	-8.4	-10.9
Lithuania	6.6	4.8	-0.2	-5.8	-8.4	-10.9	-13.3	-15.6	-17.9	-19.9	-21.7	-23.4
Malta	-25.7	-26.3	-29.4	-33.8	-35.8	-36.7	-37.7	-38.6	-39.5	-40.4	-41.3	-42.3
Poland	3.8	0.6	-7.6	-13.2	-15.1	-16.7	-18.3	-19.8	-21.2	-22.5	-23.8	-25.0
Romania	-13.6	-14.1	-17.1	-21.5	-23.8	-25.6	-27.2	-28.6	-30.0	-31.2	-32.4	-33.7
Slovak Republic	-5.3	-6.3	-10.8	-16.0	-17.4	-18.6	-19.7	-20.8	-21.9	-23.0	-24.0	-25.0
Slovenia	-2.4	-3.5	-7.5	-13.3	-19.0	-21.5	-23.8	-25.8	-27.7	-29.4	-30.9	-32.3
EU-N13	-0.2	-2.3	-8.1	-13.6	-15.9	-17.7	-19.5	-21.1	-22.7	-24.2	-25.6	-26.9

Annex 5: Sensitivity analysis (III): The impact of improved emission intensities in non-EU regions on emission leakage

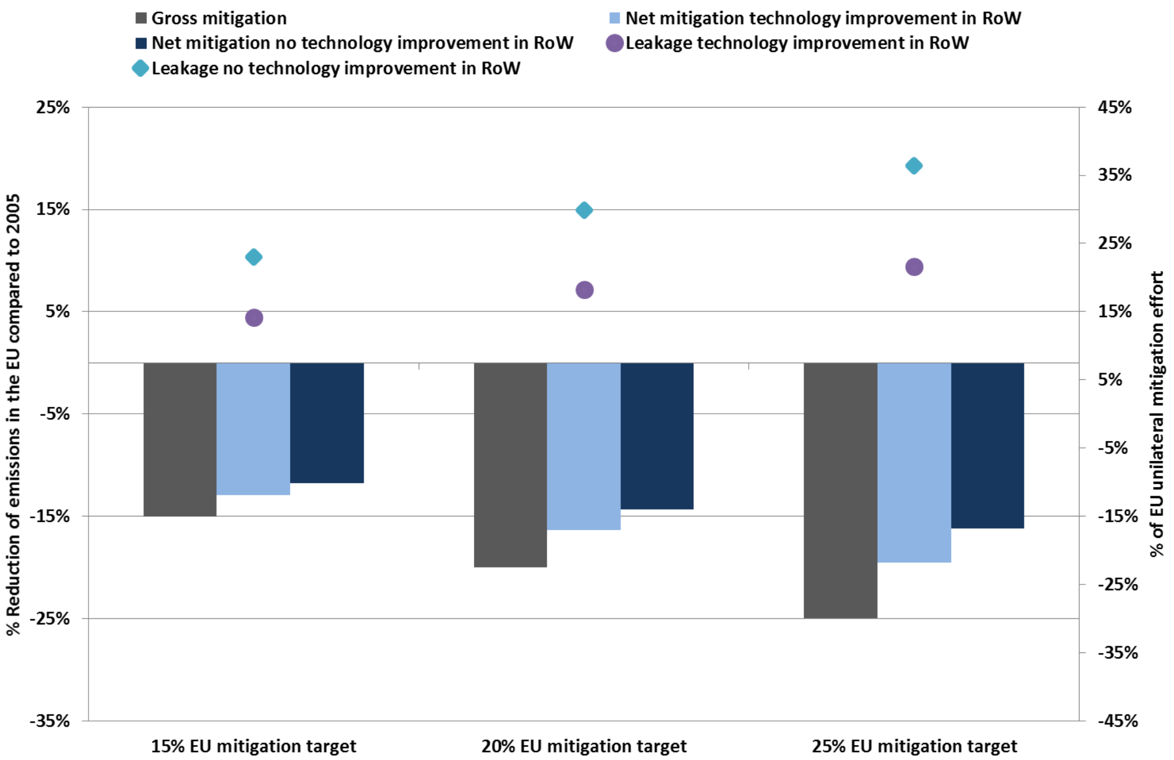
Another relevant assumption that has been checked by performing a sensitivity analysis is the impact of improved emission intensities in the rest of the world on emission leakage of EU mitigation efforts. The results presented in the main text incorporate the assumption that emission intensities in the rest of the world continue improving as they have done during the period up to 2005. For this, 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 (Jansson et al., 2010, 2014), combining data on production quantities and emission inventories from FAOSTAT (see section 3.3).

GHG emission intensity improvements in the rest of the world could be a result, for example, of developed countries allocating climate funding to GHG mitigation technology adoption. It could also happen as a consequence of GHG mitigation policies being implemented and subsidised in non-EU regions. In part, emission mitigation may also spread autonomously, for example if fertiliser efficiency improves or if anaerobic digestion plants are installed for purely economic reasons. While considering that the assumption of emission intensity improvement in the rest of the world is the most plausible one, we compare this scenario with another where there are no improvements of technology in the rest of the world as an indication of an upper-bound for emission leakage.

The results of this sensitivity analysis show that, in the absence of improvements in emission intensities in the rest of world, there is a significant increase in emission leakage when the EU unilaterally sets mitigation targets for its agricultural sector (Figure 38). In the scenarios reported in the main text, depending on how ambitious the target is, between 1 in 7 tonnes and 1 in 4 tonnes mitigated in the EU is shifted to the rest of the world, as production in the EU is replaced by imports. As expected, the largest impacts of the modelled EU mitigation efforts happen in those activities that are more emission intensive, such as beef and dairy production. Impacts on animal numbers are more significant than on production, as yield improvements partly compensate for the reduction in animal numbers.

However, in a (worst-case) scenario where no technological progress is assumed in non-EU regions, emission leakage increases to 1 in 4 tonnes shifted to the rest of the world in the 15 % EU unilateral target, and to nearly 1 in 2 tonnes in the 25 % target scenario. The effect of the increased emission efficiency in the rest of the world ranges from 9 % additional leakage points in the case of the 15 % target to 15 % in the case of the 25 % target scenario.

Figure 38: Emission mitigation and leakage as a percentage of gross mitigation for different sensitivity scenarios



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. The leakage rate is calculated as the proportion of emission reductions in the EU that are offset by increases in the rest of the world.

From a geographical perspective, the largest emission leakage is expected to occur owing to production increases in Asia and Middle and Central America, which account for nearly 60 % of all the additional emissions (Figure 39). When no improvement in emission efficiency is assumed, the largest change in the emission leakage is projected to happen in Australia and New Zealand, and Asia, where historical improvements of emission intensity have been higher.

As far as commodities are concerned, most of the emission leakage happens owing to the trade of meat products. Looking into the different types of meat traded (Figure 40), it can be seen that the largest impact of considering improvement in emission intensity occurs in relation to sheep and goat meat in relative terms (64 % impact), while the largest absolute difference happens for beef (mitigation of 3 million tonnes of CO_2 equivalents). 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 39: Distribution of leaked emissions by world region for different sensitivity scenarios

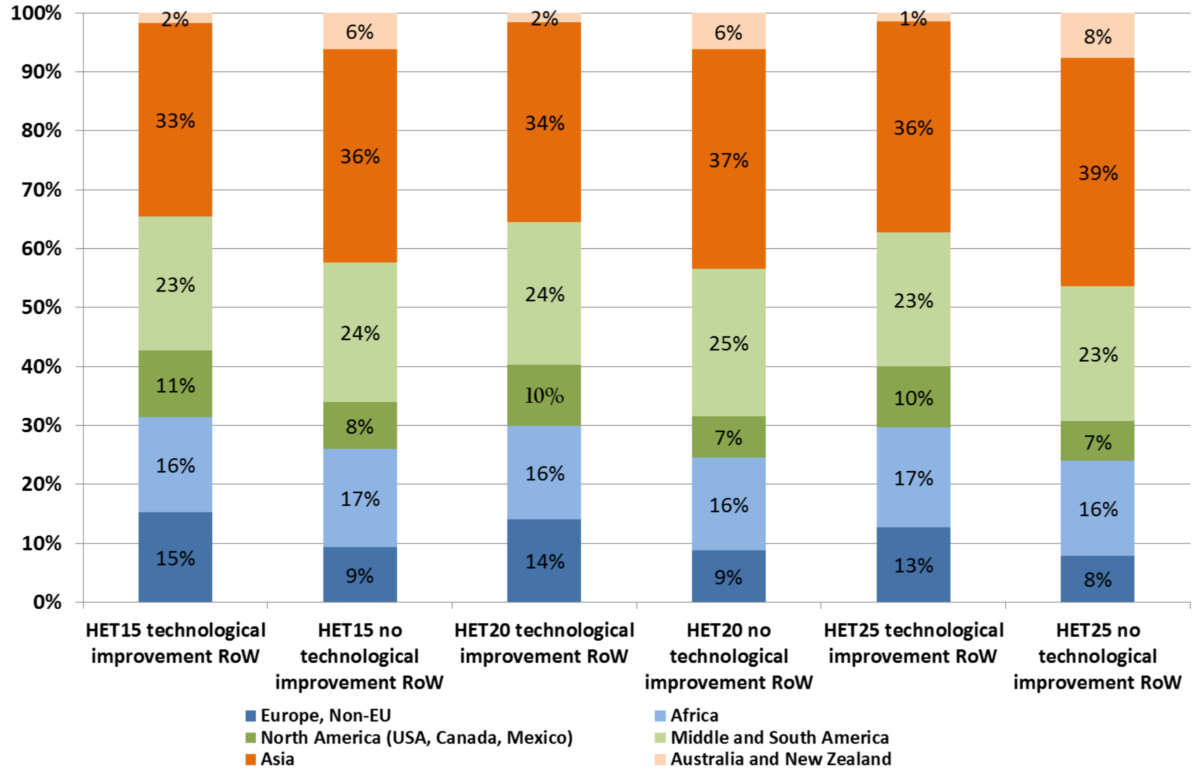
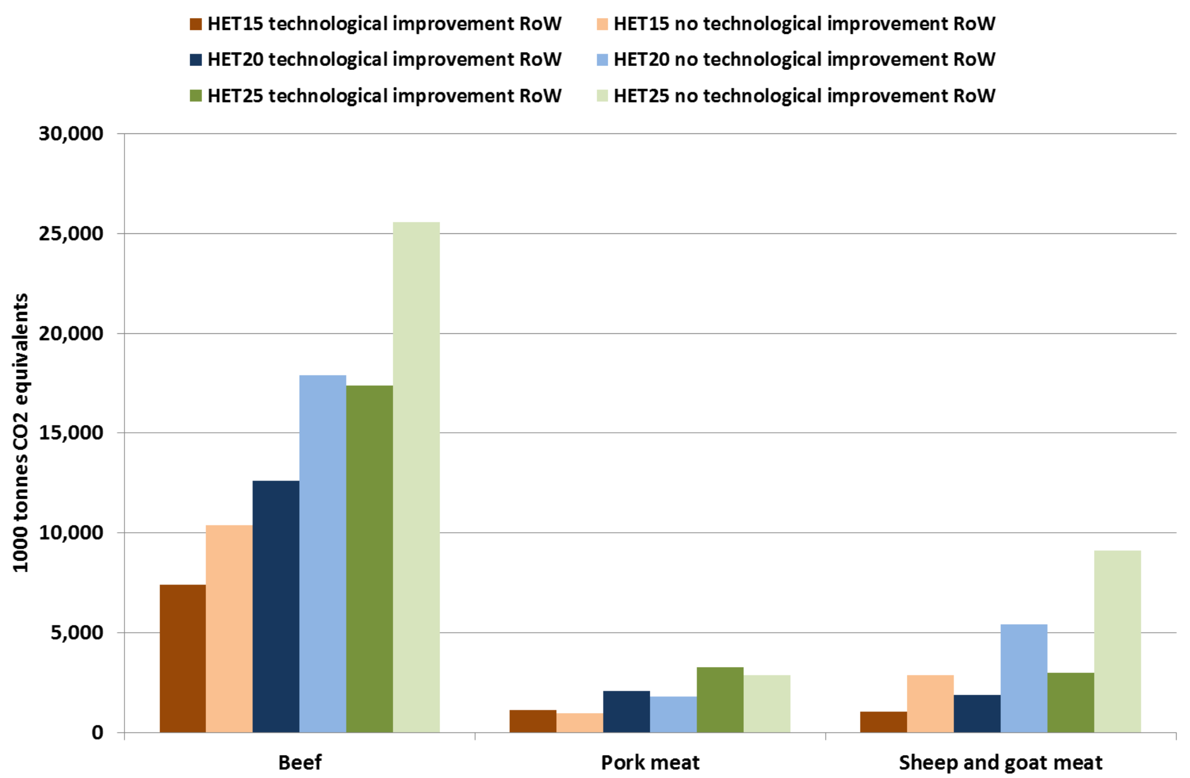


Figure 40: Emission leakage associated with traded meats under different sensitivity scenarios



List of abbreviations

CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regional Impact Analysis
CH_4	Methane
CO_2	Carbon Dioxide
CO_{2-eq}	Carbon Dioxide equivalents
CRF	Common Reporting Format
DG AGRI	Directorate General 'Agriculture and Rural Development'
DG CLIMA	Directorate General 'Climate Action'
EC	European Commission
EDGAR	Emissions Database for Global Atmospheric Research
EEA	European Environment Agency
EF	Emission Factor
ESD	Effort Sharing Decision
ETS	Emission Trading System
EU	European Union
EU-15	EU including the 15 Member States before 2004
EU-27	EU including 27 Member States (excluding Croatia)
EU-28	EU including the current 28 Member States
EU-N13	EU Member States of the 2004, 2007 and 2013 enlargements
EuroCARE	European Centre for Agricultural, Regional and Environmental Policy Research
FAO	Food and Agriculture Organization of the United Nations
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies (model/database)
GDP	Gross Domestic Product
GGELS	Greenhouse Gas Emissions from Livestock Systems (EU Project)
GHG	Greenhouse Gas(es)
GWP	Global Warming Potential
IES	Institute for Environment and Sustainability
IIASA	International Institute for Applied Systems Analysis
ILUC	Indirect Land Use Change
iMAP	Integrated Modelling Platform for Agro-economic Commodity and Policy Analysis
INDC	Indented Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IPTS	Institute for Prospective Technological Studies
JRC	Joint Research Centre
LCA	Live Cycle Assessment

LUC	Land Use Change
LULUCF	Land Use, Land Use Change and Forestry
MAC	Marginal Abatement Cost
MS	Member State(s)
N	Nitrogen
N_2O	Nitrous Oxide
NIR	National Inventory Reports
NO_2	Nitrite
NO_3	Nitrate
NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Economic Co-operation and Development
PRIMES	PRIMES Energy System Modelling
REF	Reference scenario
TRQ	Tariff Rate Quotas
UAA	Utilised Agricultural Area
UNFCCC	United Nations Framework Convention on Climate Change
USD	U.S. Dollar
USDA	U.S. Department of Agriculture
WTO	World Trade Organization

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