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An economic assessment of GHG mitigation policy options for EU agriculture

EcAMPA

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Abstract

The report presents an overview of the historical and projected development of agricultural GHG emissions in the EU. The major objective of the report is to present the improvements made in the CAPRI modelling system with respect to GHG emission accounting and especially regarding the implementation of endogenous technological mitigation options. Furthermore, the CAPRI model was applied to provide a quantitative assessment of illustrative GHG mitigation policy options in the agricultural sector, and their production and economic implications.

An economic assessment of GHG mitigation policy options for EU agriculture

- EcAMPA -

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Executive Summary

The European Commission has started to reflect on the future energy and climate change policy framework for the period post-2020. With respect to the agricultural sector the challenge for the EU is to position agriculture to further contribute to achieving reductions in GHG emissions without excessively compromising the competitiveness of EU agriculture and its ability to contribute meeting growing global food demand. Identifying the best options to tackle the challenge requires a comprehensive impact assessment of a wide range of possible technological, management and policy measures.

Within this context the European Commission launched in 2013 the project 'Economic assessment of GHG mitigation policy options for EU agriculture' (EcAMPA). The objectives of the project were: (1) Providing a description of the historical development of agricultural GHG emissions in the EU. (2) Improving the CAPRI (Common Agricultural Policy Regional Impact Analysis) modelling system with respect to GHG emission accounting and especially regarding the implementation of endogenous technological mitigation options. (3) Applying the improved CAPRI model to provide a quantitative analysis of illustrative GHG mitigation policy options for EU agriculture.

It is important to stress that the project results have to be seen in the light of the specific assumptions made. For instance, different assumptions on the availability and uptake of technological mitigation options, and agricultural productivity growth inside and outside the EU could significantly alter the scenario results.

Agriculture's GHG emissions currently account for 10 % of total EU GHG emissions

The study follows the Common Reporting Format (CRF) of the United Nations Framework Convention on Climate Change (UNFCCC), where 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 fertilizers) are attributed to other sectors and hence, unless specifically indicated otherwise, not considered in the report at hand.

According to official inventories of the Member States, GHG emissions in the source category 'agriculture' accounted for 10% of total EU GHG emissions in 2011. The share of the agricultural emissions in total national GHG emissions varies considerably between EU Member States (between 31% in Ireland and 2% in Malta), depending on the typology as well as relative size and importance of the agricultural sector. Main sources of the EU's agriculture emissions are nitrous oxide emissions from agricultural soil management (representing 52% of the total agriculture emissions in the EU; mainly due to the application of manure and mineral nitrogen fertilizer), methane emissions from enteric fermentation (32%; mainly from cattle and sheep) and emissions from manure management (16%; methane and nitrous oxide emissions during storage and treatment of manure). Over the last two decades agricultural GHG emissions decreased by 23% at aggregated EU level, from about 600 million tonnes CO_2 equivalents in 1990 to about 460 million tonnes CO_2 equivalents in 2011. In most of the Member States more emission decrease was achieved during the 1990s (-16%), whereas the reduction path significantly slowed down in the time

period between 2001 and 2011 (-7%). The general decrease in EU GHG emissions can be attributed to several factors, most of all to productivity increases and a decrease in cattle numbers, as well as improvements in farm management practices and also developments and implementation of agricultural and environmental policies.

Modelling approach and selected technological mitigation options

To calculate the GHG emission scenarios, the CAPRI modelling system was further developed and employed. CAPRI is an economic comparative-static agricultural sector model with a focus on the EU-27 (at Member State and NUTS-2 level), but also covering global agricultural production and trade. CAPRI endogenously calculates activity-based agricultural GHG emission inventories and therefore can define GHG emission effects of agriculture in response to changes in the policy or market environment. In this study the calculation of the agricultural emission inventories in the CAPRI model has been further improved. Furthermore, a first attempt was made to endogenise the choice among a selected set of technological mitigation options within the CAPRI model.

For the selection of the CAPRI technological GHG mitigation options, the GAINS database was used, as it already provides mitigation technologies and their cost structure. The following technologies were considered in the model as options that can be voluntarily applied by farmers: (i) farm-scale and community-based anaerobic digestion: manure and slurry storage under anaerobic conditions to produce methane-containing biogas; (ii) use of nitrification inhibitors to increase the efficiency of the nitrogen applied and at the same time reduce nitrous oxide emissions from mineral fertilisers; (iii) a better timing of fertilization, i.e. crop need/uptake and the applying of mineral fertilizer and manure are more geared to each other which can lead to higher yields and/or lower fertilizer requirements; (iv) precision farming as a crop management concept to respond to inter- and intra-field variability in crops; and (v) changes in the composition of animals' diet (feed): altering the feed mix of ruminant animals while keeping a required nutritional intake, which enables a reduction of methane emissions produced during the animals' digestive process.

Other technical and management based GHG mitigation options were not considered in this study because the technology or necessary information was not identified in the GAINS database, or the share of land under a commodity and its technological mitigation potential in the EU is rather negligible (e.g. rice cultivation), the share of the tackled mitigation source in agricultural GHG emissions is rather small (e.g. agricultural field burning) or the technology is assumed to be not available commercially by 2030, i.e. not within the projection period of this study (e.g. specific animal genetic improvements aimed at methane reduction, vaccination against methanogenic bacteria in livestock rumens).

Scenario set-up

The reference and mitigation policy scenarios take into account the Common Agricultural Policy (CAP) as it was known when the analysis was conducted, i.e. the measures of the CAP Reform 2014-2020 are not considered as the exact implementation of some of the measures were still negotiated at MS level. The projection year for all scenarios is 2030 and in all scenarios farmers have the possibility to voluntarily apply the covered technological mitigation measures.

To investigate the impact of putative measures introducing mandatory targets for GHG reduction in agriculture, a total of six scenarios were built. Two values for GHG emission caps were set (at MS and NUTS2 level), requiring reductions of agricultural GHG emissions of 19% or 28% respectively by 2030 compared to the year 2005. For each of the two cap values, scenarios simulate either a homogenous distribution of emission caps without trade in emission permits (HOM19 and HOM28) or with trade in emission permits (HOM19ET and HOM28ET). Furthermore, a heterogeneous distribution of emission caps (HET19 and HET28) is modelled, based on the distribution key of the Effort Sharing Decision (ESD).

In addition, alternative scenarios were tested in which no mandatory targets are in place but subsidies for the voluntary uptake of the technological mitigation measures are introduced. Three scenarios with subsidies of 30% (SUBS30), 60% (SUBS60) and 90% (SUBS90) were tested.

All policy scenarios are purely illustrative and do not reflect policy measures that are already agreed on or are under formal discussion. The purpose was to test the feasibility of the improved CAPRI model.

Reference scenario: total EU agricultural GHG emissions are not significantly lowered by 2030 compared to 2005

The evolution of agricultural GHG emissions in the reference scenario is driven by general market developments and in some cases the voluntary application of technological mitigation options (as some farmers apply them if they result in positive income effects). In this scenario, by 2030 agricultural GHG emissions for the EU-27 are just a mere 0.2% below year 2005 levels. However, the projection results are quite diverse between the Member States. The reference scenario indicates that business as usual might not be enough to trigger reductions in aggregated EU agricultural emissions over the medium-term.

Scenarios with mandatory targets: GHG emission reduction effects

Emission reductions are quite straightforward in the scenarios with the homogenous reduction targets without trade in emission permits (HOM19 and HOM28) because the respective 19% and 28% emission reduction obligations (compared to the year 2005) are met by definition at EU-27 and also at Member State level.

When trade in emission permits is introduced the majority of Member States (18 Member States in HOM19ET and 20 Member States in HOM28ET) show lower net emission reductions compared to the respective scenarios without tradable emission permits. This indicates that these Member States are net buyers of emission permits, i.e. it was more beneficial to buy emission permits instead of reducing GHG emissions by as much as initially obliged to by the homogenous cap. Net buyers are nine EU-15 and nine EU-N12 Member States in HOM19ET and ten each in HOM28ET.

In the scenarios with heterogeneous reduction targets (HET19 and HET28), the commitments of some EU-N12 MS imply that they could actually increase their emissions compared to the year 2005. However, other constraints, related to agricultural production and not to emission reduction targets, prevent some of the MS from fully using their allowed emission possibilities (this effect is particularly pronounced in Romania).

Scenarios with mandatory targets for GHG reduction: effects on agricultural production

Under the setting of this study, the largest part of the required GHG reduction is realised by a quantitative adjustment of agricultural production (herd size, yield and cultivated hectares), especially in the livestock sector. Given the assumptions made on the technological mitigation options available in 2030, the impact of a change in livestock production management and technology on GHG emissions is rather limited. However, it has to be kept in mind that while effects of changes in the feed mix on enteric fermentation via digestibility have been included in the analysis, some technologies directly addressing enteric fermentation of cattle, which represents 32% of the agricultural GHG emissions, have not been considered (e.g. vaccination, propionate precursors). Moreover, the share of livestock production that can apply the considered technology options is sometimes very limited and country specific. On the other hand, almost 100% of EU crop production would potentially use the provided technological mitigation options.

Within the livestock sector, the herd size of beef meat activities is most affected in all scenarios with mandatory targets for GHG reduction, because reductions of other activities, for example dairy cows, would entail higher economic losses per unit of emission savings. Reductions in herd size of beef meat are between 31% (HOM19) and 54% (HET28). However, the significant decreases in beef herd sizes are not fully reflected in supply, which decreases between 18% (HOM19ET) and 31% (HET28). The fact that supply in beef meat activities decreases less than herd size indicates a change in herd structure, with an overall increase in productivity per cattle. This change is also reflected at Member States level, but projection results show that in the scenarios with homogenous reduction targets both beef herd size and production decreases are more pronounced in the EU-N12 than in the EU-15. On the other hand, in the HET scenarios reduction effects in beef herd and production are less pronounced in the EU-N12 than in the EU-15, which is due to the generally lower emission reduction commitments in the EU-N12, allowing the EU-N12 to partially compensate for the decreases in beef activities in the EU-15. Changes in dairy herd size and milk production generally show the same pattern as projected for the beef sector, albeit at a lower level (with decreases in EU-27 milk production between 4% in HOM19ET and 9% in HOM28). Utilised agricultural area in the EU-27 is projected to be reduced in all scenarios (between 6.5% in HOM19ET and 13% in the HOM28 scenarios). Hectares under production as well as supply decrease for all arable activities in the EU-27, but fodder activities are hit most by the mitigation policies (which is directly related to the decreases in the livestock sector). EU-27 cereal area and production are also negatively affected in all scenarios, with decreases in production between 3% in HET19 and 8% in HOM28.

Scenarios with mandatory targets for GHG reduction: economic effects

As a consequence of the large production decreases in the EU described above, the EU's trade balance is projected to worsen for almost all agricultural products, and especially the EU net trade position for beef deteriorates. Due to the declines in EU production, which are not compensated by equal imports, all producer prices in the EU are projected to increase. Scenario results indicate that, in most EU regions, the increase in producer prices and yields would offset the farmers' income loss caused by reductions in area and animal heads, leading to increases in total agricultural income at aggregated EU-27 level between 14% (HOM19ET) and 27% (HOM28) at EU-27 level. However, between 5% (HOM28ET and HET28) and 11% (HOM19) of the NUTS-2 regions show negative income effects in the scenarios with emission reduction targets. Moreover it has to be kept in mind that it is likely that some farmers might have to leave the sector if they are not able to cope with the GHG mitigation obligations. Evidently only farmers remaining in the sector would benefit from the projected increase in total agricultural income. At EU level a major economic impact is reduced consumer welfare due to higher prices for food, especially for meat and dairy products (e.g. consumer prices for beef meat are projected to increase by up to 31%).

Scenarios with subsidies for the voluntary uptake of GHG mitigation technologies

In an alternative set of scenarios, the introduction of a subsidy for the voluntary uptake of GHG emission mitigation technologies is simulated without mandatory emission reduction targets. Results indicate, as expected, a higher uptake of technologies compared to the reference scenario. Scenario results also show that the modelled subsidies can be considered as production neutral, as they entail virtually no production changes in the EU. However, even with an increased uptake of the selected mitigation technologies the overall effect on EU GHG mitigation is relatively limited, reaching just an additional 4.5% reduction of GHG emissions (compared to the reference scenario) when subsidising 90% of the costs of these technologies.

Emission leakage may considerably downsize the net effects of EU mandatory targets on global GHG reduction

Finally, the model was used to look at the effects of the scenarios tested on global GHG emissions (i.e. including non-EU countries). This analysis reveals that scenarios considering EU-only mandatory targets do not necessarily lead to emission reductions at the global level, due to emission leakage. If production declines in the EU are not accompanied by equivalent decreases in EU consumption, part of the EU production decrease may be replaced by imports, which can cause emissions outside the EU that may considerably downsize the net effect on global GHG reduction. The scenario results suggest that, even though they do not involve mandatory emission reduction targets, the modelled subsidies for the implementation and use of the considered GHG mitigation technologies might achieve similar net effects with regard to global emissions as the scenarios with mandatory GHG reduction targets. This can be explained by the negligible impact of the modelled subsidies on the EU agricultural markets, which entail no production changes in the rest of the world and hence no emission leakage effects.

Conclusions and further research

The results of the illustrative scenarios with mandatory targets show important impacts on agricultural production in the EU, especially for the livestock sector. Scenario results also indicate that the more flexible the mitigation policy instruments are implemented the less are the production effects on aggregated EU level and hence also any potential emission leakage effects. However, it is important to keep in mind that these scenarios are hypothetical and exploratory. Additionally, the study only considers a restricted number of mitigation technologies as applicable during the projection period. Last but not least, the estimation of emission leakage effects has several limitations that could lead to over-estimation (e.g. lack of consideration of technological change over time and indirect effects of intensity changes in non-EU regions).

In general, the results of this study should be considered as indicative and understood within the specific framework of assumptions of the study. Additional phases of this project are expected to follow and focus on the improvement of the proposed modelling framework and above mentioned caveats. More specifically, a further improvement of the CAPRI modelling system is expected regarding the choice of technological mitigation options for the farming sector, the consideration of carbon dioxide emissions and a more comprehensive estimation of emission leakage effects. Furthermore, more information on possible implementation details of the EU climate change framework for 2030 will be included in follow-up studies.

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List of Abbreviations

BAS	Baseline (Scenario)
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regional Impact Analysis
CDM	Clean Development Mechanism
CH_4	Methane
CO_2	Carbon Dioxide
$CO_{2\text{-}eq}$	Carbon Dioxide equivalent
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
ETSA	Emission Trading Scheme (only) for Agriculture (hypothetical scheme)
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-N12	EU Member States of the 2004 and 2007 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
HET19	Heterogeneous Emission Reduction by 19% Scenario
HET28	Heterogeneous Emission Reduction by 28% Scenario
HOM19	Homogenous Emission Reduction by 19% Scenario
HOM19ET	Homogenous Emission Reduction by 19% with Emission Permits Trading Scenario
HOM28	Homogenous Emission Reduction by 28% Scenario

HOM28ET	Homogenous Emission Reduction by 28% with Emission Permits Trading Scenario
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
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	Nitrate
NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Economic Co-operation and Development
PRIMES	PRIMES Energy System Modelling
REF	Reference scenario
SMP	Skimmed Milk Powder
SUB30	Mitigation Technology Subsidy of 30% Scenario
SUB60	Mitigation Technology Subsidy of 60% Scenario
SUB90	Mitigation Technology Subsidy of 90% Scenario
TC	Transaction Cost
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

1 Introduction

This report is part of the project 'Economic assessment of GHG mitigation policy options for EU agriculture' (EcAMPA)', which is carried out within the iMAP Administrative Agreement between DG AGRI and JRC (AA N °AGRI- 2013 – 0223). The work is being realised through a close cooperation between JRC-IPTS (leading institution), JRC-IES, EuroCARE GmbH and the Swedish University of Agricultural Sciences.

1.1 Background

The European Union has set itself the target to reach a 20% reduction of greenhouse gas (GHG) emissions by 2020 compared to 1990. In the current EU climate and energy package of 2009 a decision was taken to distribute the 20% reduction obligation for the EU-27 to Member States (under the Effort Sharing Decision, ESD) and industry (under the Emission Trading Scheme, ETS). The agricultural sector, as non-CO_2 emitter, was included under the ESD and, therefore, excluded from the ETS (cf. Council of the European Union, 2009). Thus, with regard to the ESD in the EU, Member States have binding GHG emission abatement targets that also include agriculture. However, up to now no explicit policy measures are implemented that would specifically force GHG emission abatement in the agricultural sector.

The European Commission has started to reflect on the future energy and climate change policy framework for the period post-2020 (European Commission, 2013; 2014a). With respect to the agricultural sector the challenge for the EU is to position agriculture (and the dependent agri-food sector) to further contribute to achieving climate targets, growing food demand and trade commitments, while at the same time ensuring that its competitiveness is not excessively compromised (European Commission, 2011). Identifying the best options to tackle the challenge requires a comprehensive impact assessment of a wide range of possible technological, management and policy measures.

In 2012, the JRC-IPTS published a quantitative assessment of the possible impact of the implementation of specific policy options (such as regionally homogeneous or differentiated emissions caps and a specific emissions trading scheme for agriculture) to mitigate GHG emissions in the EU.[1] Within the context of forthcoming policy discussions for the setting up of the EU climate change framework for 2030, DG AGRI asked for an updated and further elaborated study of the potential impacts of future options for the EU's climate policy on the agriculture sector.

1.2 Objective and scope of the report

This report presents an overview of the historical and projected development of agricultural GHG emissions in the EU. The main objective of the report is to present the improvements made in the CAPRI (Common Agricultural Policy Regional Impact Analysis) modelling system

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[1] The report is published as Pérez Dominguez et al. (2012): Agricultural GHG emissions in the EU: An Exploratory Economic Assessment of Mitigation Policy Options. JRC Scientific and Policy Reports, European Commission, Seville.

with respect to GHG emission accounting. Furthermore, the report presents the application of the CAPRI model to provide a quantitative analysis of illustrative GHG mitigation policy options in the agricultural sector, and their production and economic implications. Several scenarios have been built, covering a range of mitigation policy options as well as specific technological abatement measures and scenarios that consider subsidy schemes to support the voluntary uptake of the technological measures. The target year for the simulation scenarios is 2030, which is also the time horizon for the new EU climate policy framework. At the time of the study, no decision was taken on how EU MS would implement emission targets. The examined GHG mitigation policy scenarios are intended to explore what could happen if policies would be implemented that explicitly force farmers in the EU-27 to reach GHG emission reductions that are in line with the roadmap for moving to a low-carbon economy in 2050. The policy scenarios are quite rigid and give much less flexibility than could be expected in more likely policy scenarios.

It has to be highlighted that the policy scenarios are all hypothetical and illustrative, and they do not reflect mitigation policies that are already agreed on or currently under formal discussion in the EU.

To project and quantify GHG emissions in the agricultural sector as well as production and economic impacts linked to mitigation of GHG emissions, the CAPRI modelling system has been employed. Apart from general model updates and adjustments made for the project, we improved the CAPRI modules for the accounting of GHG emissions and for emission leakage. Furthermore, we further enhanced the CAPRI modelling system by implementing some specific endogenous GHG mitigation technologies. This means that farmers can choose to voluntarily apply one or more GHG mitigation technologies, with the CAPRI model calculating endogenously both the uptake by the farmers of the mitigation technologies as well as the resulting effects on agricultural GHG emissions, income, production and markets.

In the report 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 and the endogenous technological GHG mitigation options (Chapter 3). The mitigation potential of the technological options is outlined in Chapter 4. The background and definition of the scenarios is presented in Chapter 5 and the results of the model simulations in Chapter 6. Chapter 7 presents an assessment of the effects of introducing emission leakage into the scenario analysis and in Chapter 8 some concluding remarks are given.

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

This chapter presents a brief overview on agricultural GHG emissions in the EU, including their historical developments according to key sources. All data is based on the latest available official data compiled by the European Environment Agency (EEA) and reported by the EU to the UNFCC (see EAA database set v14, published on 04 July 2013).

2.1 Overview on agricultural GHG emissions in the EU

EU Member States have to report their GHG emissions annually according to a common reporting framework of the United Nations Framework Convention on Climate Change (UNFCCC). Following the UNFCCC reporting scheme, the inventory for the agricultural sector includes emissions of methane (CH_4) and nitrous oxide (N_2O). It has to be noted that 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, like those from the manufacturing of animal feed and fertilizers are included in the category 'industrial processes' (IPCC, 2006).

Thus, the overall GHG emissions that are related to agricultural production and activity are actually greater than those reported under the category 'agriculture' (CRF Sector 4)[2] in the UNFCCC official inventories. Accordingly, GHG emissions related to agriculture are higher if the emission accounting is done in form of a life cycle assessment (LCA). The LCA approach helps to get a more thorough idea of emissions created by agricultural products as it considers also emissions caused by the production of the inputs used.[3] However, official emission values of the national inventories are not reported based on products but based on activities. Therefore this overview on agricultural GHG emissions in the EU follows the reporting on emissions by the EU Member States and is based on the latest available official data compiled by the European Environment Agency (EEA)[4] and reported by the EU to the UNFCCC (see EAA database, 2013).

According to GHG inventories of the EU-28 Member States, GHG emissions in the source category agriculture accounted for a total of 464 million tonnes of CO_2 equivalents in 2011, of which about 42% were methane emissions and 58% nitrous oxide emissions. This represented 10.1% of total EU-28 GHG emissions in 2011 (cf. Figure 1). When also looking at

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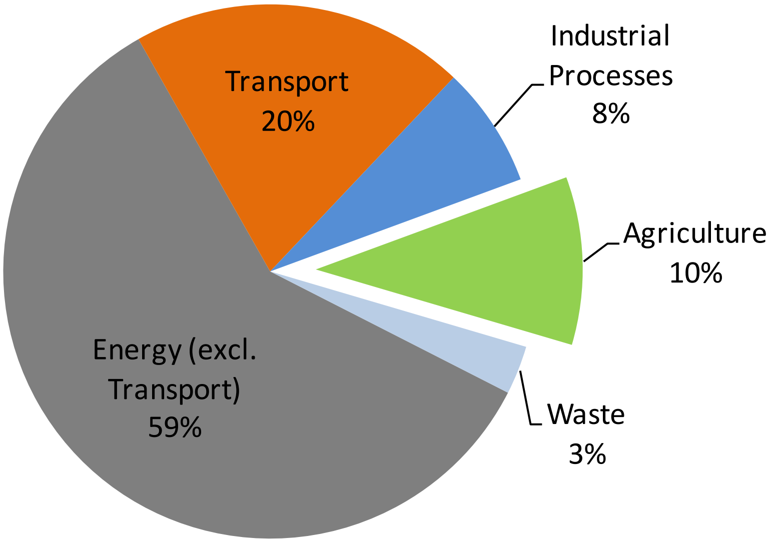
[2] In the course of the study at hand the UNFCCC source categories have been changed and 'agriculture' became CRF Sector 3.

[3] For example, in the GGELS project the CAPRI model was adapted to account for product based GHG emissions from agriculture in order to quantify GHG emissions of EU livestock production in the form of a life cycle assessment. For more information see Leip et al. (2010).

[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 Directorate-General Climate Action (DG CLIMA).

the agricultural emissions of cropland and grassland categories not attributed to the 'agriculture' but the LULUCF category, it can be seen that net emissions from agricultural land accounted for 68 million tonnes CO_2 in 2011 in the EU-28. This comprises emissions of 80 million tonnes CO_2 from croplands and removals of 12 million tonnes CO_2 from grasslands (i.e., croplands are a net source and grasslands a net sink of GHG emissions).

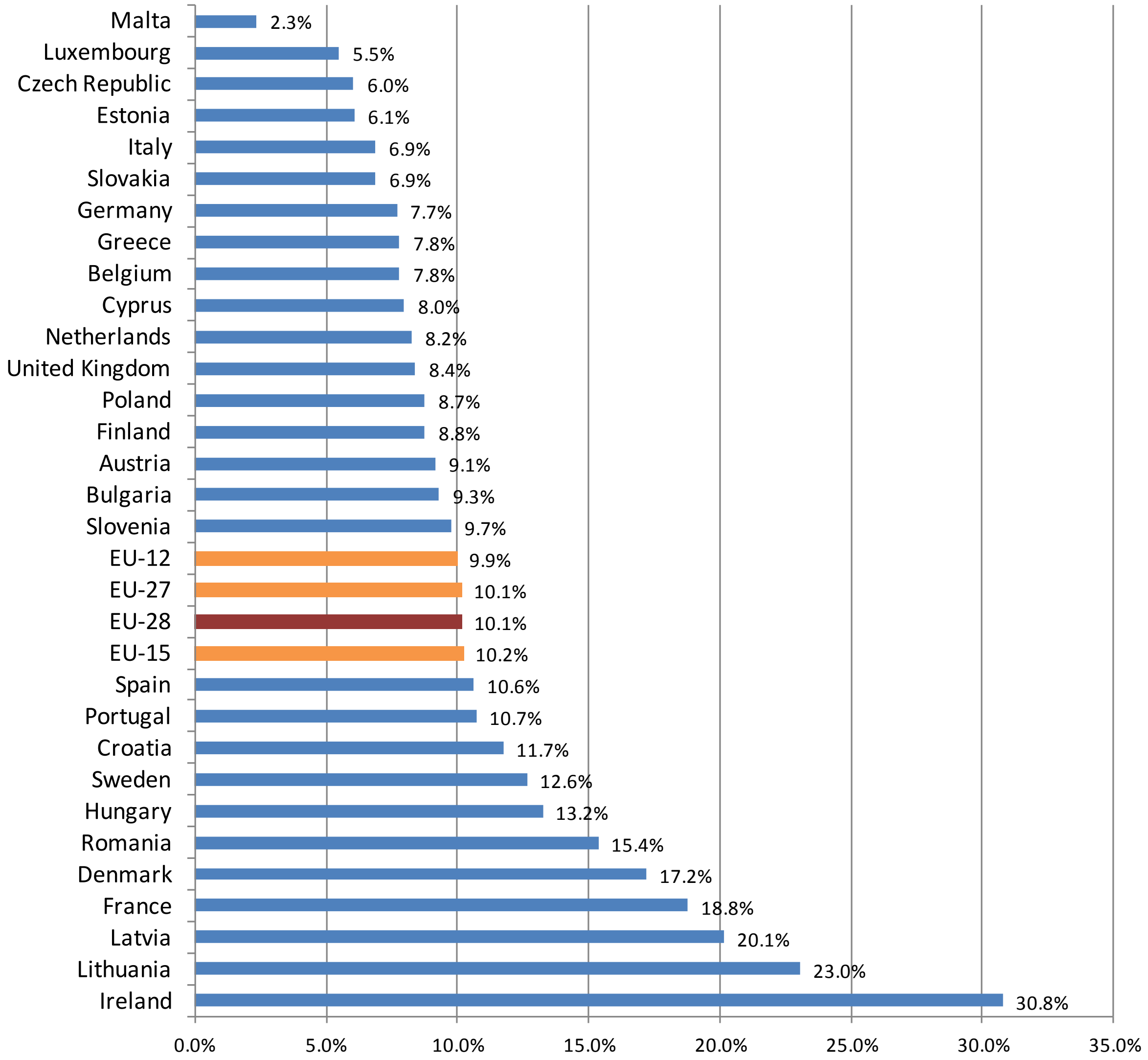
Figure 1: Share of agricultural GHG emissions in total emissions (excl. LULUCF) in the EU-28, 2011



Source: EEA database (2013)

The share of the agricultural emissions in total national GHG emissions varies considerably within the EU Member States, depending on the relative size and importance of the agricultural sector. The share is highest in Ireland (31%) and Lithuania (23%) and lowest in Malta (2%), Luxembourg, the Czech Republic and Estonia (all about 6%) (cf. Figure 2).

Figure 2: Share of agricultural GHG emissions in total national emissions in EU MS, 2011



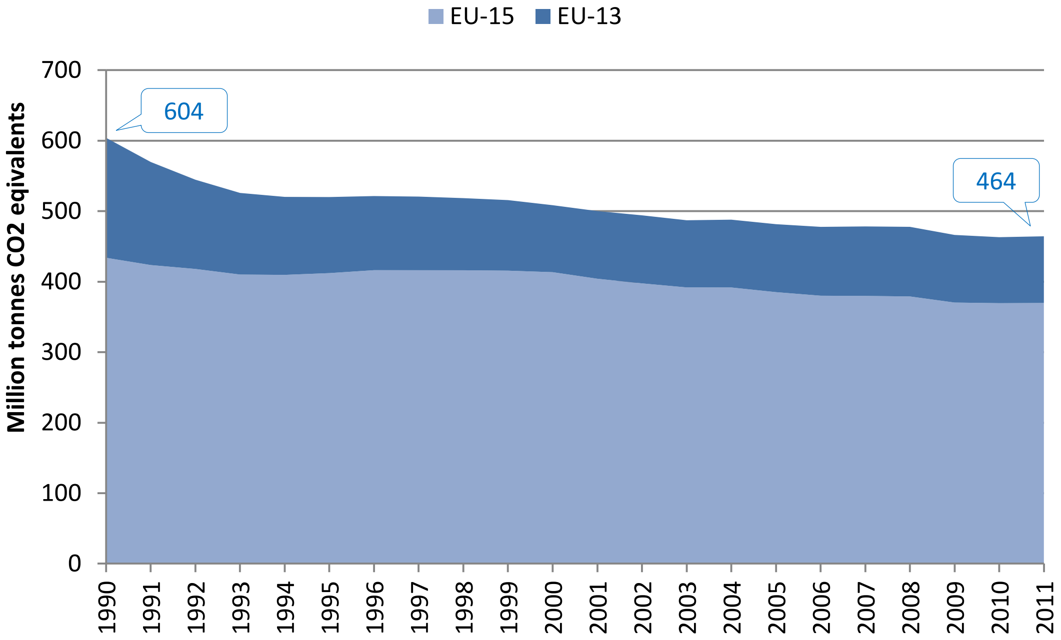
Source: EEA database (2013)

2.2 Historical developments of agricultural GHG emissions in the EU

The historical developments of agricultural GHG emissions show a rather steady downward trend on the aggregated EU-28 level of -23%, from about 604 million tonnes CO_2 equivalents in 1990 to about 464 million tonnes CO_2 equivalents in 2011 (cf. Figure 3).

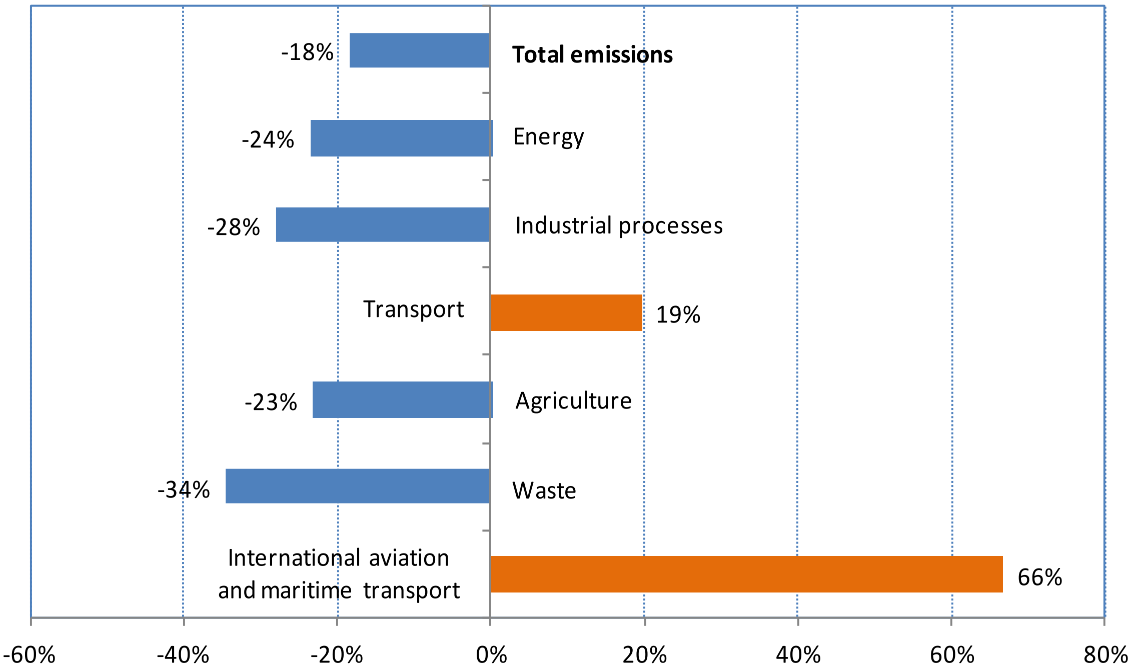
When comparing the relative changes in agricultural GHG emissions to the development of emissions in other sectors of the EU-27, it can be seen that the relative reductions in agriculture between 1990 and 2011 are less than those achieved in the sectors waste and industrial processes, but higher than the trend in total EU GHG emissions (cf. Figure 4).

Figure 3: Development of agricultural GHG emissions in the EU, 1990-2011



Source: EEA database (2013)

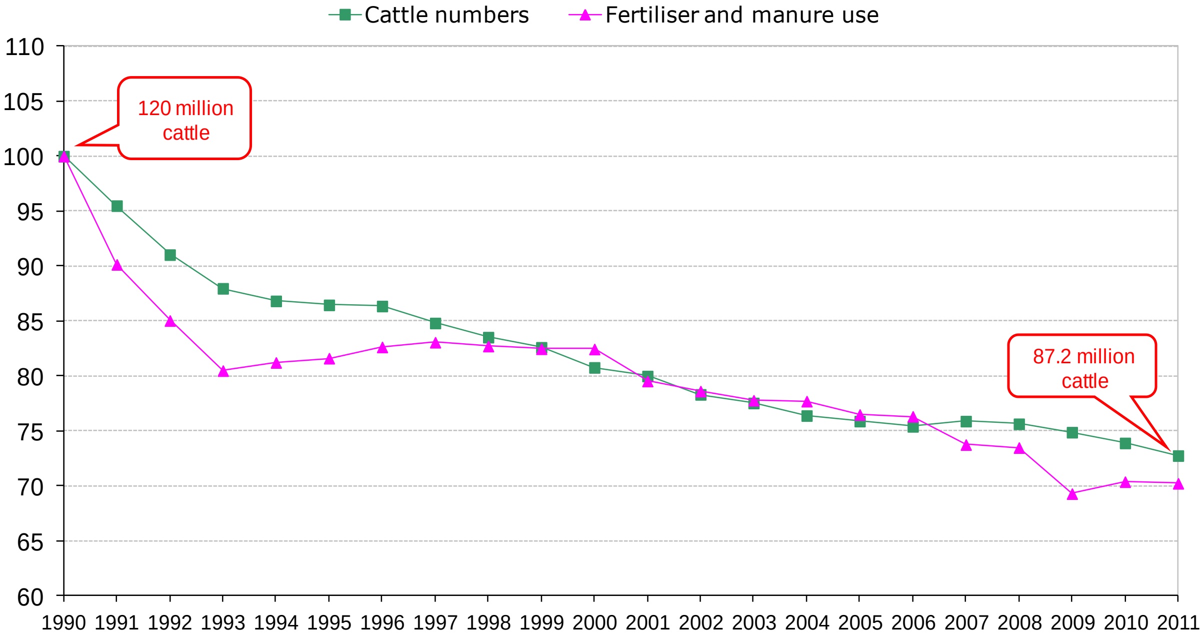
Figure 4: Changes in EU-27 GHG emissions by sector, 1990–2011



Source: EEA database (2013)

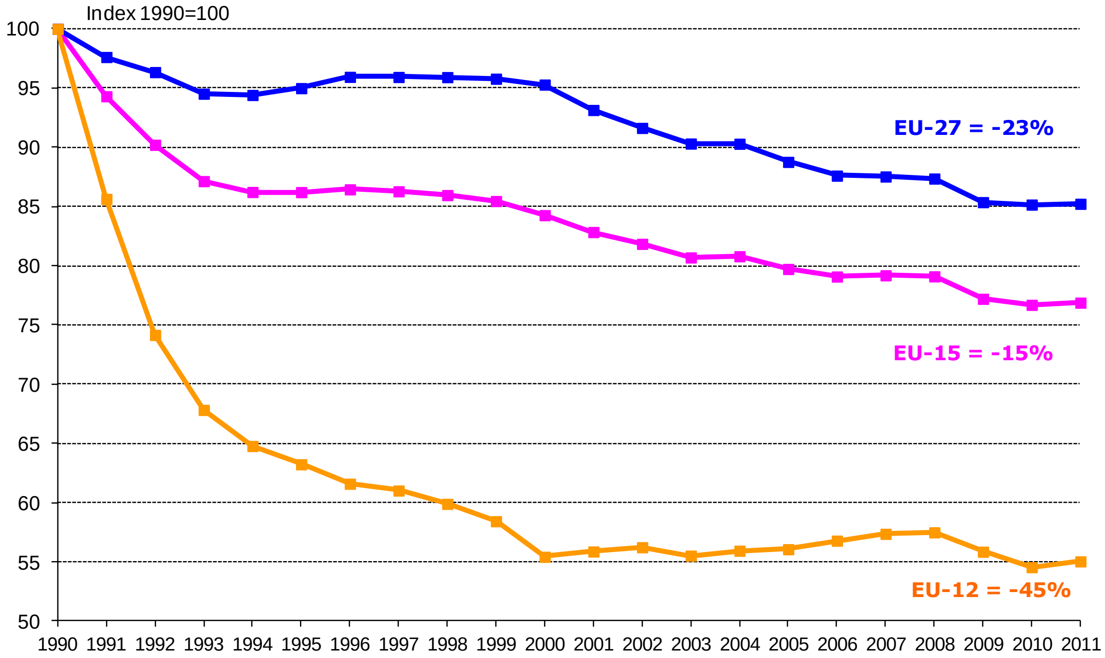
The decrease in agricultural GHG emissions can be attributed to several factors, most of all to productivity increases and a decrease in cattle numbers, as well as improvements in farm management practices and also developments and implementation of agricultural and environmental policies (cf. Figure 5). Furthermore, the developments have been considerably influenced by adjustments of agricultural production in the EU-N12 following the changes in the political and economic framework after 1990 (cf. European Commission, 2009; EEA, 2013; cf. Figure 6).

Figure 5: Trend in cattle numbers and use of fertilisers, EU-27 (Index 1990=100)



Source: EEA database (2013)

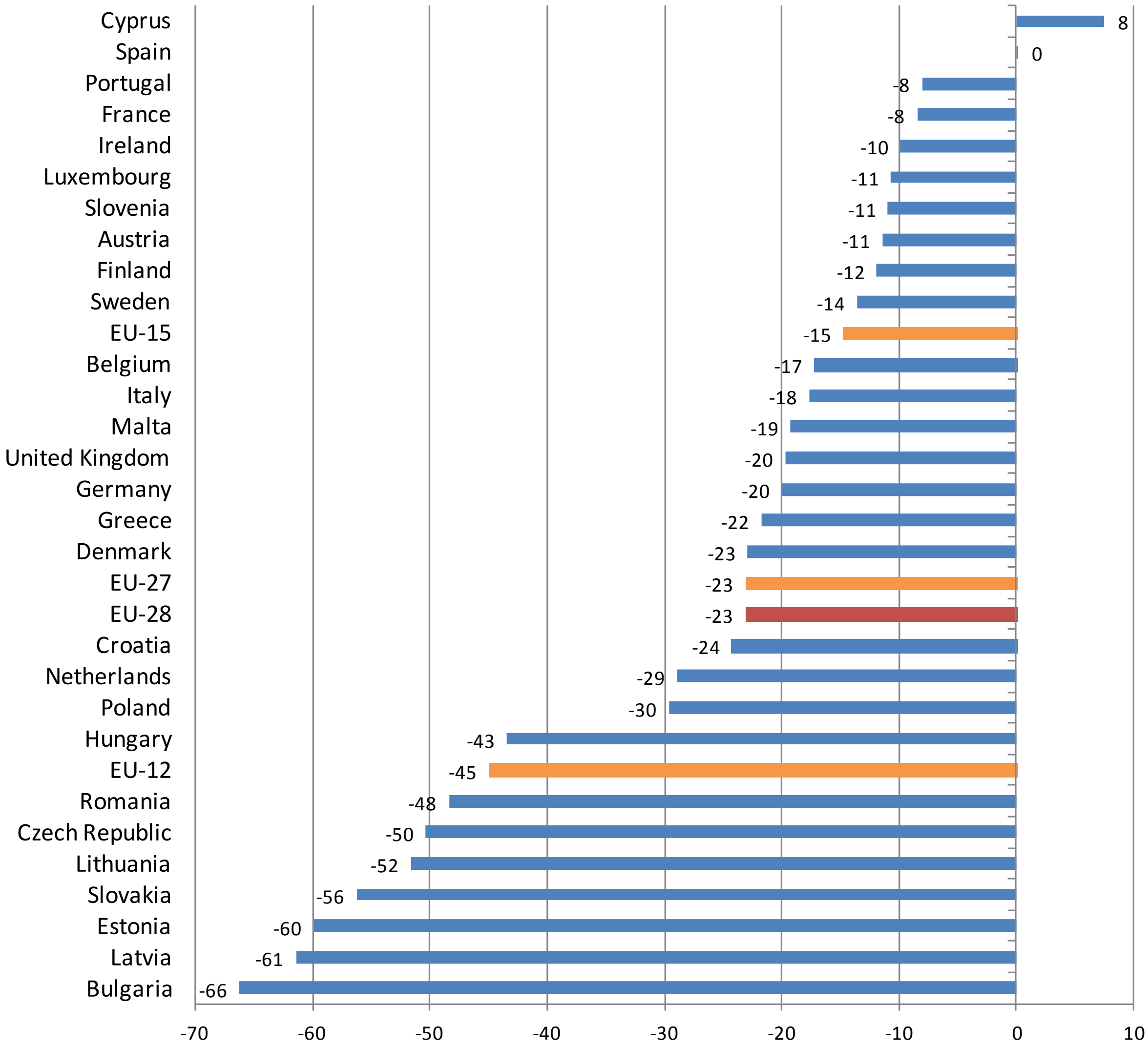
Figure 6: Trend of agricultural GHG emissions in the EU-27 (Index 1990=100)



Source: EEA database (2013)

In Figure 7 the average change of agricultural GHG emissions in terms of CO_2 equivalents between 1990 and 2011 are presented per MS. On average, the emissions have been reduced by 23% in the EU-28, with largest relative reductions reported for eight EU-N12 MS, headed by Bulgaria (-66%), Latvia (-61%) and Estonia (-60%). In the same time period, the EU-15 MS reduced their agricultural GHG emissions by 15%, with the biggest relative reductions reported for the Netherlands (-29%), Denmark (-23%) and Greece (22%). Overall, 26 of the MS reported reductions in the absolute levels of agricultural GHG emissions between 1990 and 2011, and while there is no change in the total level of agricultural GHG emissions reported in Spain, Malta is the only MS where the emissions actually increased during this time period (+8%).

Figure 7: Change in agricultural GHG emissions per MS, 1990-2011 (%)

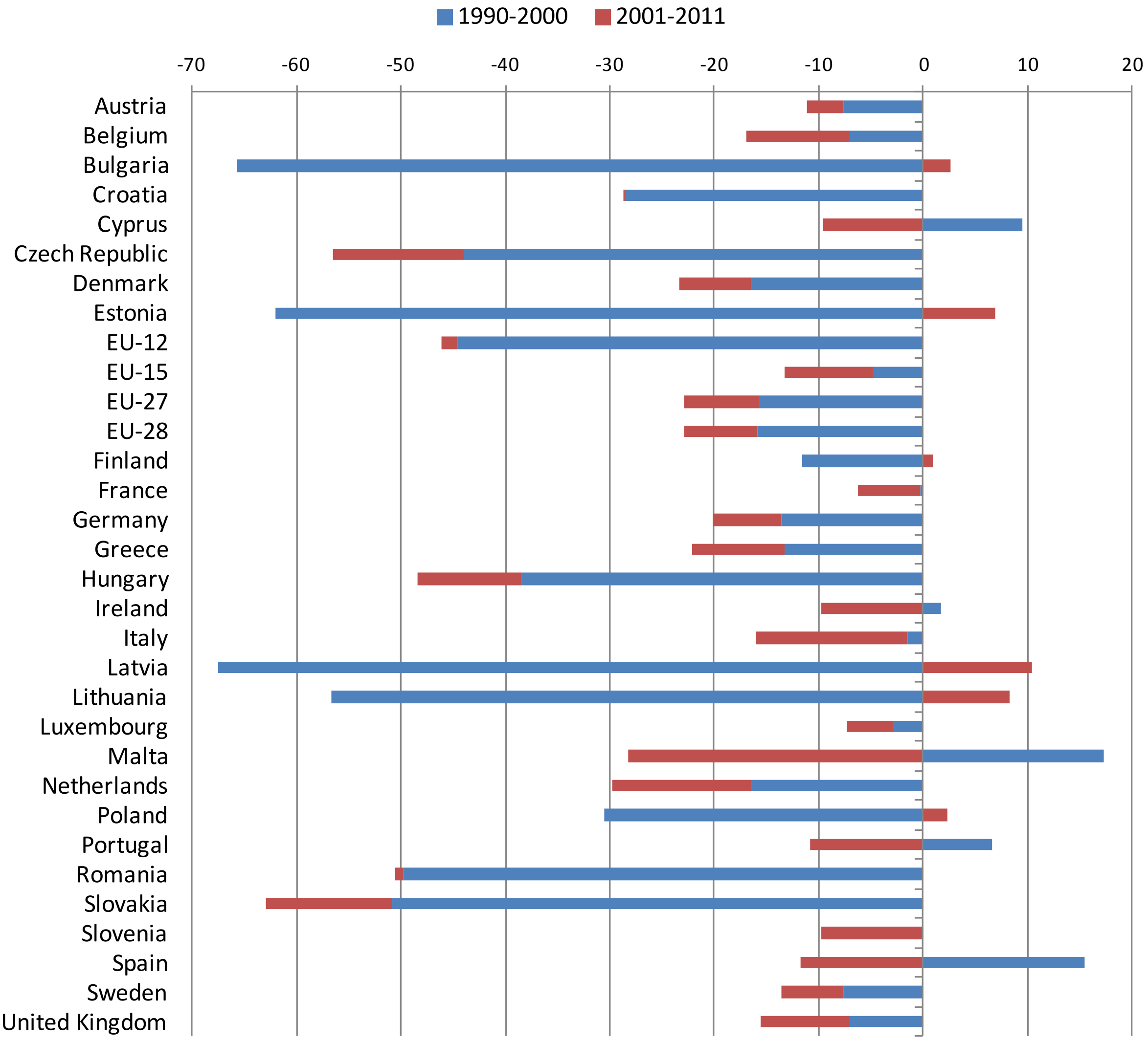


Source: EEA database (2013)

Looking closer into the developments of agricultural GHG emissions per MS, dividing the trend into two time periods shows that the major part of the decreases was achieved in the period between 1990 and 2000 and that in most MS the reduction path significantly slowed down in the time period between 2001 and 2011. This holds especially for the EU-N12 MS, where due to the restructuring process GHG emissions decreased on the aggregate level by

44.6% between 1990 and 2000, but only by about 1.5% between 2001 and 2011. On the contrary, agricultural GHG emissions in the aggregated EU-15 level decreased more between 2001 and 2011 (-8.5%) than between 1990 and 2000 (-4.7%) (cf. Figure 8).

Figure 8: Development of agricultural GHG emissions per MS, 1990-2000 and 2001-2011 (%)

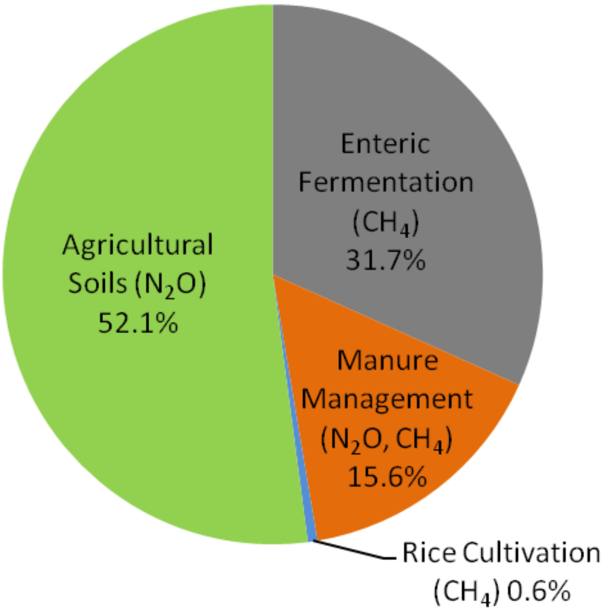


Source: EEA database (2013)

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

Looking at the specific sources of the 464 million tonnes of CO_2 equivalent emissions in the agricultural sector of the EU-28 in 2011, the share is divided between the following source categories: agricultural soils (52%), enteric fermentation (32%), manure management (15%) and rice cultivation (1%) (cf. Figure 9). It should be noted that field burning of agricultural residues accounts for emissions of about 0.8 million tonnes of CO_2 equivalents, but are not included in the figure below as this only represents a share of 0.2% in overall agricultural emissions in the EU-28.

Figure 9: Breakdown of agricultural GHG emissions in the EU-28, 2011



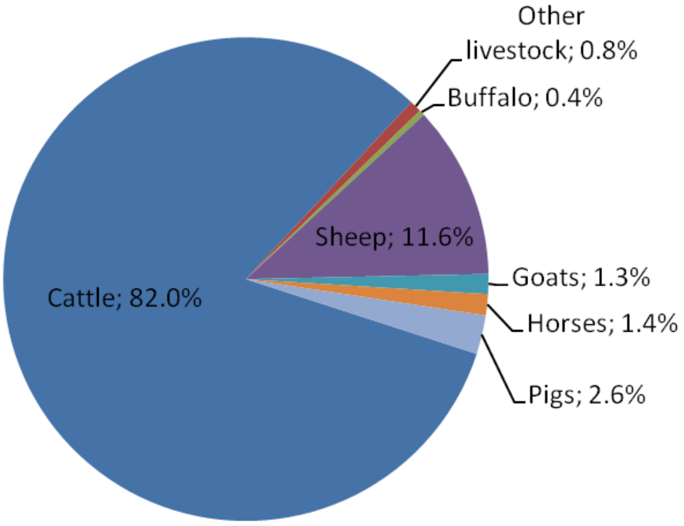
Source: EEA database (2013)

Enteric fermentation

Enteric fermentation occurs when CH_4 is produced as microbial fermentation takes place in the digestive processes of livestock. The type of digestive system of the animal has a significant influence on the rate of methane emission, with ruminant livestock (e.g. cattle, sheep) being a major sources of methane, whereas non-ruminant livestock (e.g. horses, mules) and monogastric livestock (pigs) produce only moderate amounts of methane. Apart from the digestive tract of the animal, the overall amount of methane released depends on further animal and feed characteristics, like age and weight of the animal and the quality and quantity of the feed consumed (IPCC, 2006).

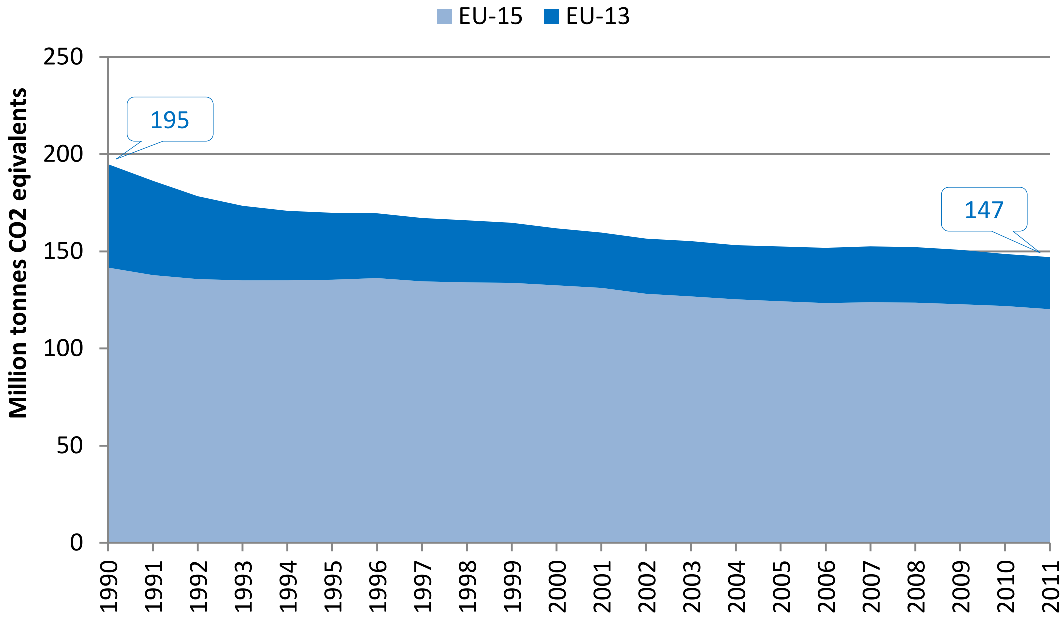
Enteric fermentation accounted for about 147 million CO_2 equivalents (32%) of the overall agricultural emissions in the EU-28 in 2011. Most of the emissions in the source category enteric fermentation stem from CH_4 emissions from cattle (about 82%) and sheep (about 12%) (cf. Figure 10). Thus, enteric fermentation from cattle is the largest single source of CH_4 emissions in the EU-28, accounting for 26% of all agricultural emissions in the EU-28 in 2011. The share of enteric fermentation from sheep in overall EU-28 agricultural emissions is 3.7%. Between 1990 and 2011, methane emissions from enteric fermentation decreased by 24.5% (about 48 million tonnes CO_2 equivalents) in the EU-28 (Figure 11).

Figure 10: Breakdown of emissions in the category enteric fermentation, EU-28 (2011)



Source: EEA database (2013)

Figure 11: Development of EU emissions in the category enteric fermentation, 1990-2011

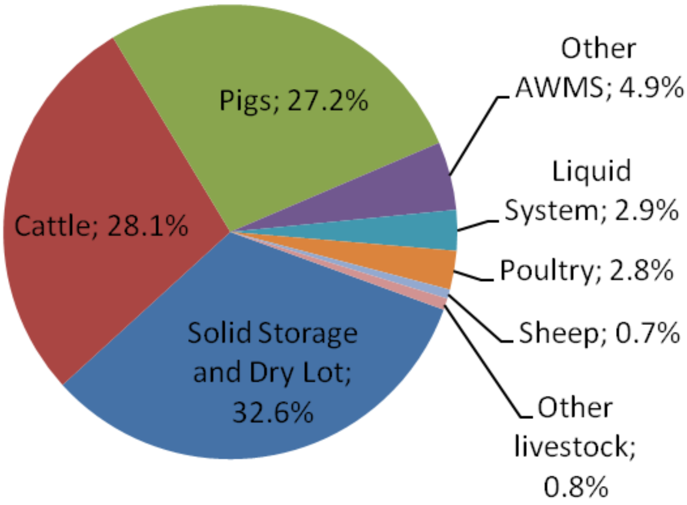


Source: EEA database (2013)

Manure management

Livestock manure (dung and urine) is the second most important source of methane emissions in agriculture. However, during the storage and treatment of manure (i.e. before it is applied to land or otherwise used) not only methane but also nitrous oxide emissions are emitted. CH_4 is produced from the decomposition of manure under anaerobic conditions while N_2O is produced under aerobic or mixed aerobic/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. CH_4 emissions are categorised according to animal type sources 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).

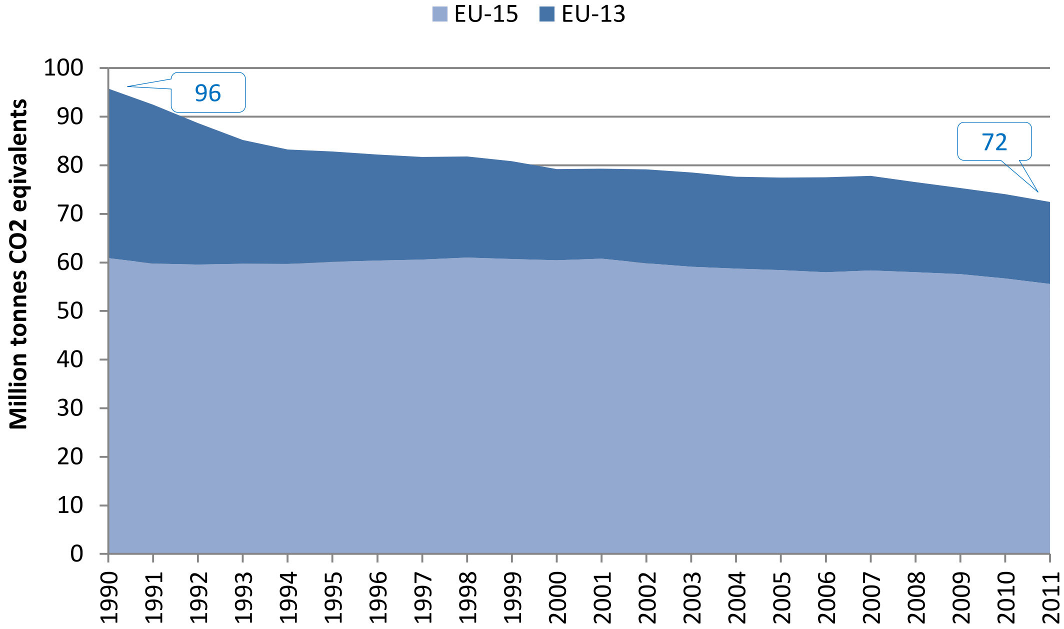
Figure 12: Breakdown of emissions in the category manure management, EU-28 (2011)



Note: AWMS = Animal Waste Management Systems
Source: EEA database (2013)

Manure management accounts for approximately 72.4 million CO_2 equivalents (15.6%) of the total agricultural emissions in the EU-28. CH_4 emissions from manure management are a key source category for cattle and pigs in many MS, with emissions of 20.3 million tonnes of CO_2 equivalents of manure management coming from cattle and 19.7 million tonnes of CO_2 equivalents from pigs in the EU-28 (respectively representing a share of 4.4% and 4.2% in overall EU-28 agricultural emissions). N_2O emissions from the manure storage system 'solid storage and dry lot' accounted for 23.7 million tonnes of CO_2 equivalents in the EU-28 in 2011 and thus for 5.1% of the total agricultural emissions. The breakdown of emissions in the category manure management for the EU-28 in the year 2011 is presented in Figure 12. EU-28 emissions in the source category manure management decreased by 24.3% (about 24.4 million tonnes of CO_2 equivalents) between 1990 and 2011 (Figure 13).

Figure 13: Development of EU emissions in the category manure management, 1990-2011



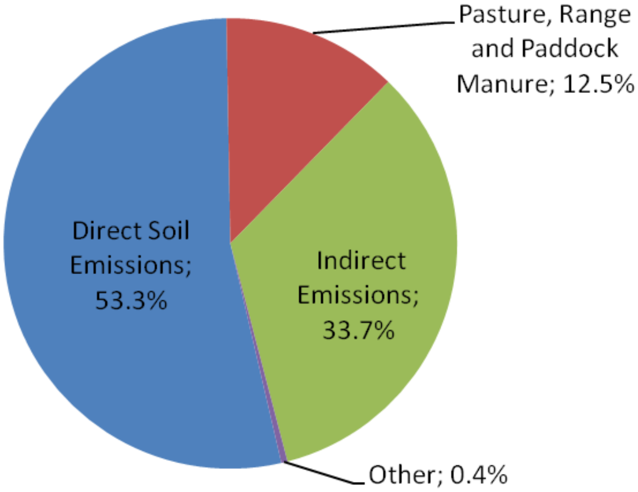
Source: EEA database (2013)

Agricultural soils

The natural processes of nitrification and denitrification produces nitrous oxide in soils. A variety of agricultural activities increase mineral N availability in soils directly or indirectly and thereby increase the amount available for nitrification and denitrification, and thus 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 to soil: application of mineral nitrogen fertilizer, application of managed livestock manure, biological nitrogen fixation and nitrogen returned to the soil by the process of mineralization of crop residues. The subcategory 'pasture, range and paddock manure' covers N_2O emissions from manure deposited by grazing animals. 'Indirect emissions' reports on N_2O emissions that occur through the following two pathways: (1) nitrogen volatilization and subsequent atmospheric deposition of applied/mineralized N, and (2) nitrogen leaching and surface runoff of applied/mineralized N into groundwater and surface water (IPCC, 2006).

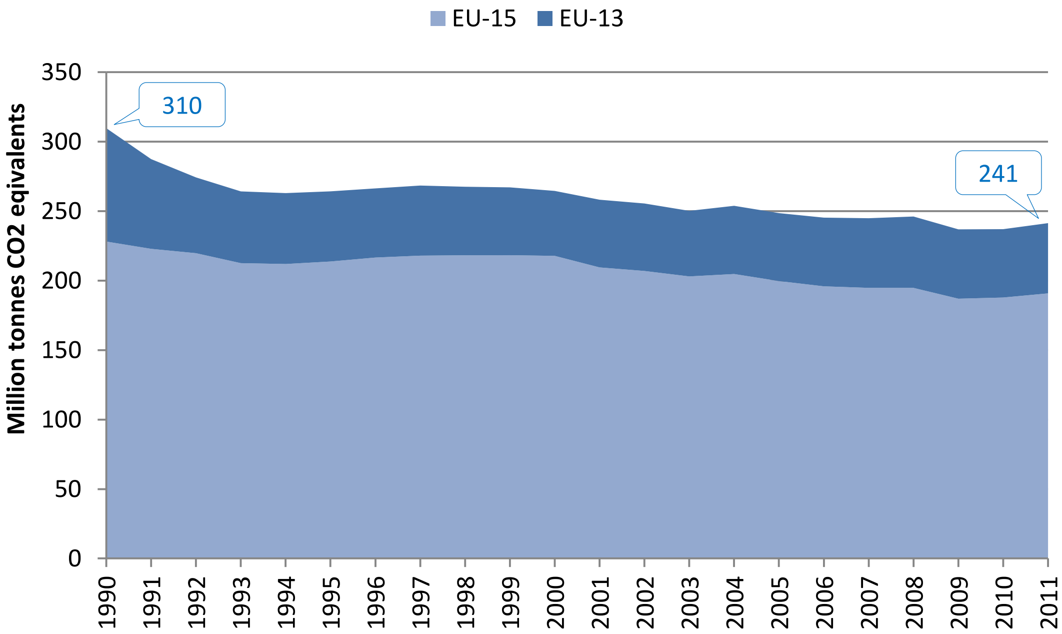
Agricultural soil management accounted for a total emission of about 241 million tonnes CO2 equivalents in the EU-28 in 2011, representing 52% of total agricultural emissions. Emissions in this source category consist largely of direct N_2O emissions from agricultural soils (53%), occurring from the application of mineral nitrogen fertilisers and organic nitrogen from animal manure, and accounting for 28% of the overall emissions attributed to EU-28 agriculture. N_2O emissions from 'pasture, range and paddock manure' account for 12.5% of emissions in this category and represent a share of 6.5% in total agricultural emissions, while the share of N_2O indirect emissions from soils account for 17.5% of the total agricultural emissions in the EU-28 in 2011 (cf. Figure 14). Between 1990 and 2011, EU-28 emissions in the source category agricultural soils decreased by 22% (about 69 million tonnes CO2 equivalents) (Figure 15).

Figure 14: Breakdown of emissions from the category agricultural soils, EU-28 (2011)



Source: EEA database (2013)

Figure 15: Development of EU emissions in the category agricultural soils, 1990-2011



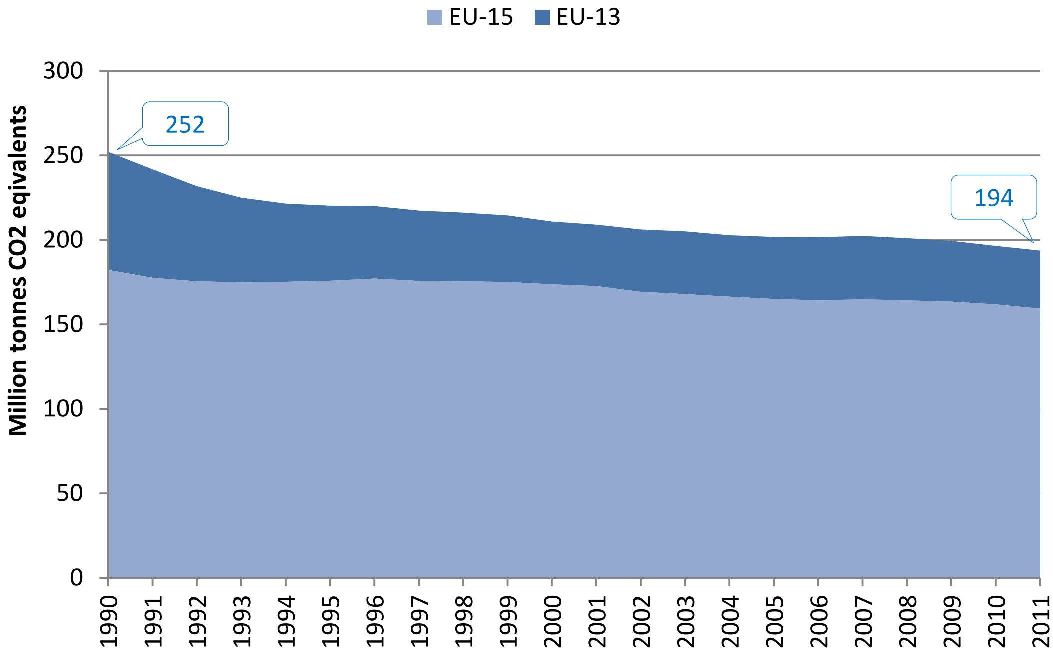
Source: EEA database (2013)

2.4 Agricultural emissions of methane and nitrous oxide and their development

As highlighted above the two major sources of methane emissions from agriculture are enteric fermentation by ruminants and emissions from manure management. The main sources for agricultural nitrous oxide emissions are manure management and emissions from agricultural soils, which can be subdivided in a) direct soil emissions from the application of mineral fertilizers and animal manure, direct emissions from crop residues and the cultivation of histosols, ii) direct emissions from manure produced in the meadow during grazing, and iii) indirect emissions from nitrogen leaching and runoff, and from nitrogen deposition (cf. IPCC, 2006).

During the period 1990-2011 the emissions of methane from the agricultural sector decreased by 23.2% in the EU-28 (from 252 to 194 million tonnes CO_2 equivalents) (cf. Figure 16).

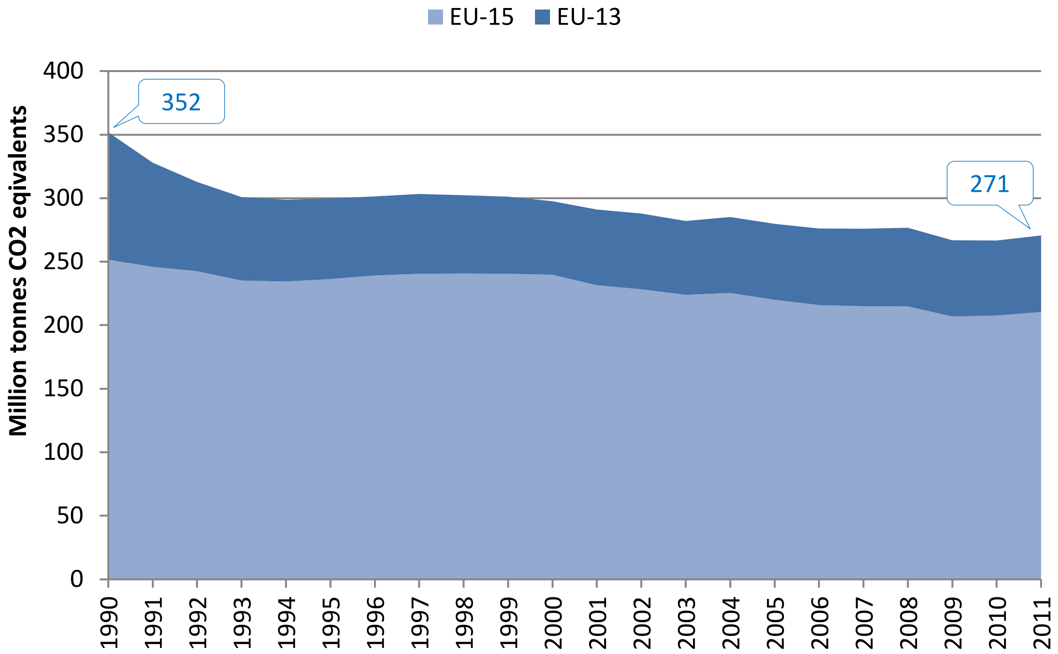
Figure 16: Development of methane emissions in EU agriculture, 1990-2011



Source: EEA database (2013)

Agricultural emissions of nitrous oxide have been reduced by 23.1% in the EU-28 between 1990 and 2011 (from 352 to 271 million tonnes CO2 equivalents) (cf. Figure 17).

Figure 17: Development of nitrous oxide emissions in EU agriculture, 1990-2011



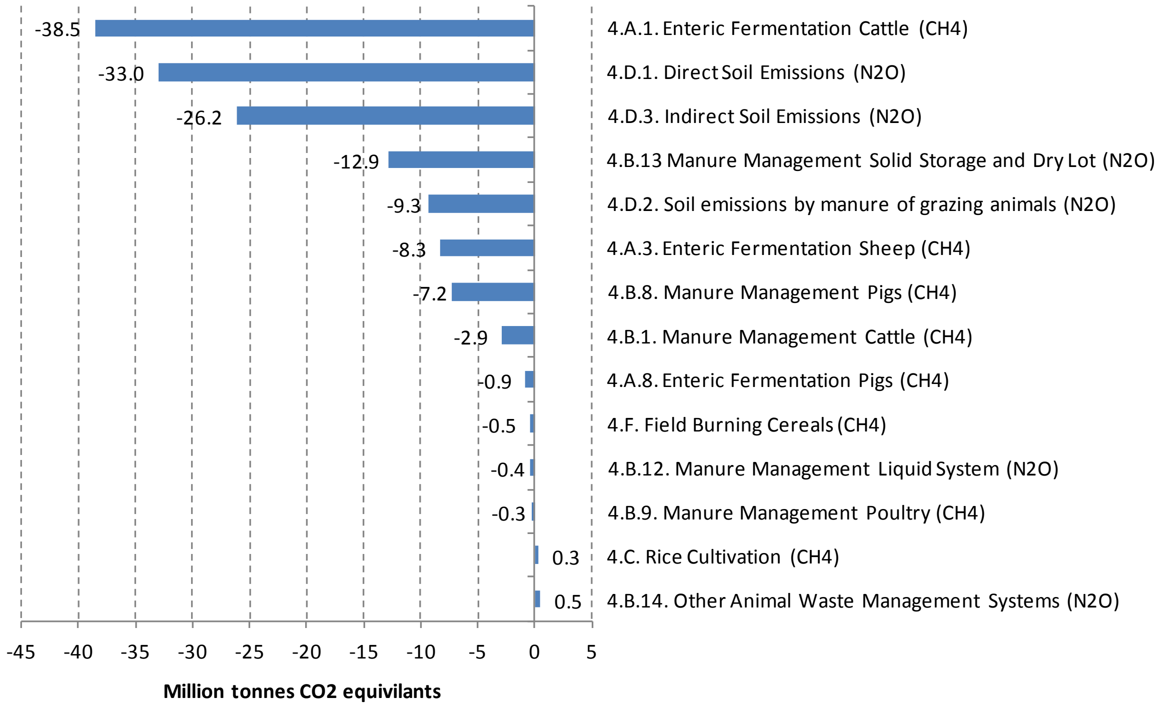
Source: EEA database (2013)

Looking closer into the developments in the key source categories of agricultural GHG emissions shows where the largest absolute decreases in methane and nitrous oxide occurred in the EU-28 between 1990 and 2011 (Figure 18).

The largest absolute reductions of methane occurred in the key source enteric fermentation of cattle, decreasing by 38.5 million tonnes CO_2eq (-24%) between 1990 and 2011 at EU-28 level, followed by a decrease of 8.3 million tonnes CO_2eq (-33%) in enteric fermentation of sheep. The main driving force for methane emissions from enteric fermentation is the number of animals, which decreased for both cattle and sheep in the EU-28 over the time period considered. The decrease in animal numbers not only lead to decreases in enteric fermentation but also comprised decreased methane emissions from the management of their manure. Thus the reductions in methane emissions can mainly be attributed to significant decreases in cattle numbers, which was influenced by the CAP and also followed increases in animal productivity (milk and meat) and related improvements in the efficiency of feed use. In this context also the adjustments in agricultural production in the EU-N12 following the changes in the political and economic framework after 1990 have been important.

Largest absolute reductions of nitrous oxide emissions in the EU-28 occurred in soil emissions, with direct soil emissions decreasing by 33 million tonnes CO_2eq (-20%) and indirect soil emissions by 26.2 million tonnes CO_2eq (-24%) between 1990 and 2011. The main driving force of nitrous oxide emissions from agricultural soils is the application of mineral nitrogen fertilizer and organic nitrogen from animal manure. Thus, the decrease in nitrous oxide emissions from soils is mainly attributable to reduced use of mineral nitrogen fertilizers (following productivity increases but also influenced by the CAP) and decreases in the application of animal manure (a direct effect of declining animal herds).

Figure 18: Largest absolute changes in GHG emissions by EU agricultural key source categories, 1990–2011 (million tonnes CO_2 equivalents)



Source: EEA database (2013)

3 Overview of the methodological framework and the endogenous technological GHG mitigation options

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

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

In this study, we make a first attempt to endogenise the choice among a selected set of technological mitigation options within the CAPRI model (Britz and Witzke, 2012). The agents in the regional programming models representing the European farm sector are assumed to maximise their income. However, various factors constrain the level of production activities (e.g., the number of animals or hectares cultivated with some crop) and the use of mitigation technologies. These factors include land availability, fertilization requirements of the cropping systems versus organic nutrient availability, feed requirements in terms of dry matter, net energy, protein, and fibre for each animal (Pérez Dominguez, 2006; Leip et al., 2010). Furthermore, policy restrictions, including emission targets, as used in this impact analysis, may also influence decision making.

In previous GHG mitigation policy analyses in CAPRI (Pérez Dominguez et al., 2012; Leip et al., 2010) technological mitigation options (i.e., technical and management-based GHG mitigation measures) were not endogenously implemented. For this study, the calculation of the agricultural emission inventories in the CAPRI model has been further improved, and, for the first time, also specific endogenous GHG mitigation technologies have been introduced in the optimisation procedure: farm scale anaerobic digestion, community anaerobic digestion, nitrification inhibitors, timing of fertilization, precision farming, and changes in the composition of animals' diet (feed).

The general CAPRI modelling approach is outlined in section 3.1. In section 3.2 the calculation of agricultural GHG emission inventories in CAPRI is briefly described. A short description of the technological mitigation options considered is presented in section 3.3. Section 3.4 presents a brief description of the CAPRI spatial trade model for emission permits in agriculture, used for one of the mitigation policy scenarios.

3.1 The CAPRI model

CAPRI is an economic large-scale comparative-static agricultural sector model with a focus on EU (at NUTS2, Member State and aggregated EU-27 level), covering global trade with agricultural products as well (Britz and Witzke, 2012).[5] 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 all regional agricultural activities in a Nuts 2 region (28 crop and 13 animal activities). These supply models combine a Leontief technology for intermediate inputs covering a low and high yield variant for the different production activities with a non-linear cost function which captures the effects of labour and capital on farmers' decisions. This is combined with constraints relating to land availability, animal requirements, crop nutrient needs and policy restrictions (e.g. production quotas). The non-linear cost function allows for perfect calibration of the models and a smooth simulation response rooted in observed behaviour (cf. Pérez Dominguez et al., 2009; Britz and Witzke, 2012).

The market module consists of a spatial, non-stochastic global multi-commodity model for 40 primary and processed agricultural products, covering 40 countries or country blocks. Bilateral trade flows and attached prices are modelled based on the Armington assumption of quality differentiation (Armington, 1969). The behavioural functions for supply, feed, processing and human consumption in the market module apply flexible functional forms, so that calibration algorithms ensure full compliance with micro-economic theory. The link between the supply and market modules is based on an iterative procedure (cf. Pérez Dominguez et al., 2009; Britz and Witzke, 2012).

3.2 Calculation of agricultural emission inventories in CAPRI

The specific structure of CAPRI is suitable for the analysis of GHG emissions. The regional supply models capture links between agricultural production activities in detail. The modelling system is adapted to be able to calculate activity based agricultural emission inventories. Based on the differentiated lists of production activities, inputs and outputs define GHG emission effects of agriculture in response to changes in the policy or market environment. The CAPRI model incorporates a detailed nutrient flow model per activity and region (including explicit feeding and fertilising activities, i.e. balancing of nutrient needs and availability) and calculates yields per agricultural activity endogenously. With this information, CAPRI is able to calculate endogenously GHG emission coefficients following the IPCC guidelines (cf. IPCC, 2008). The IPCC guidelines provide various methods for calculating a given emission. These methods all use the same general structure, but the level of detail at which the calculations are carried out can vary. The IPCC methods for estimating emissions are divided into 'Tiers', encompassing different levels of activity, technology and regional detail. Tier 1 methods are generally straightforward (activity multiplied by default emissions factor) and require less data and expertise than the more advanced Tier 2 and Tier 3 methods. Tier 2 and Tier 3 methods have higher levels of complexity and require more detailed country-specific information on, for example, technology type or livestock

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[5] More detailed information on the CAPRI model is documented in Britz and Witzke (2012), and can be found on the CAPRI-model homepage: http://www.capri-model.org/dokuwiki/doku.php.

characteristics. In CAPRI a Tier 2 approach is generally used for the calculations, however, for activities where the respective information is missing a Tier 1 approach is applied to calculate the GHG emissions (e.g. rice cultivation). A more detailed description of the general calculation of agricultural emission inventories on activity level in CAPRI (without the inclusion of technological mitigation options) is given in Pérez Domínguez (2006) and in the GGELS report (Leip et al., 2010). Details on the estimation of commodity-based emission factors for non-EU countries can be found in Chapter 7.

Reporting of emissions can take place by aggregating to the desired aggregation level. The output as given in this study (see Table 1) is mimicking the reporting on emissions by the EU to the UNFCCC (cf. Pérez Dominguez, 2006; Pérez Dominguez et al., 2007; Pérez Dominguez et al., 2009).

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

Economic model for mitigation modelling

The regional income maximisation may be formulated as:

$$
\begin{aligned}
&\max\ R(act) - C^T(act, fert, feed, mshar) \\
&s.t. \\
&G(act, feed, fert) \le 0 \qquad (1)\\
&0 \le mshar_{a,m,e} \le 1, \forall\, m \\
&\sum\nolimits_m mshar_{a,m,e} = 1
\end{aligned}
$$

where the regional indices are omitted and

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

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

$$
\begin{aligned}
C^T(act, fert, feed, mshar) = {} & \sum\nolimits_a act_a \sum\nolimits_{m,e} C^m(mshar_{a,m,e}) + fert_N \sum\nolimits_m C^m(mshar_{N,m,N2O\min}) \\
& + C^O(act, fert, feed)
\end{aligned}
\qquad (2)
$$

where

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

This framework involves an important simplification: the mitigation shares do not enter the constraint function G(.) nor the cost function C^O. In the case of anaerobic digestion (AD), a relevant mitigation technology targeting CH_4, this seems to be approximately correct, if we assume that the residues (containing the nitrogen and other plant nutrients from the manure and other feedstocks for AD) are returned to the soil without significant losses. The only effect of AD is then to reduce CH_4 emissions from manure and to generate income (negative cost C^m).

The assumption of no influence of mitigation on constraints and other costs is more questionable for measures to reduce N_2O emissions from fertilizer application such as precision farming or improved timing of fertilization. These measures should also influence the overall nutrient balance in the crop sector which is neglected for the time being.

Most emission types are calculated as the product of emission factors per activity level (determined as a function of yields and other characteristics) and activity levels. For some of them, mitigation measures may reduce emissions according to a factor $mfac_{a,e}$ below the standard, uncontrolled amount (= 100%). The most important example is the reduction in CH_4 emissions from manure management according to the GAINS mitigation options "farm scale and community scale anaerobic digestion plants". Formally,

$$\begin{aligned} & emi_e = \sum_a mfac_{a,e} \cdot \varepsilon_{a,e} \cdot act_a \\ & where \\ & mfac_{a,e} = \sum_m \mu_{a,m,e} \cdot mshar_{a,m,e} \end{aligned} \tag{3}$$

and

emi$_e$ emissions of type *e*.

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

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

Emissions of N_2O from synthetic fertilizers are incorporated similarly with the total use of mineral fertilizer adopting the role of emissions causing activity. Relevant mitigation technologies are nitrogen inhibitors, timing of fertilization and precision farming, as defined in the GAINS model (the mitigation technologies nitrogen inhibitors and timing of fertilization can also be combined, precision farming is assumed to include both nitrogen inhibitors and timing):

$$\begin{aligned} & emi_{N2O\min} = mfac_{N,N2O\min} \cdot \varepsilon_{N,N2O\min e} \cdot fert_N \\ & where \\ & mfac_{N,N2O\min} = \sum_m \mu_{N,m,N2O\min} \cdot mshar_{N,m,N2O\min} \end{aligned} \tag{4}$$

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

However, one of the contributions of this study is a straightforward but important modification of the "standard" Tier 2 approach. In the CAPRI model, unlike the situation in inventory calculations envisaged by IPCC (2006), feed intake and its composition are known model variables. Therefore it is possible to directly compute gross energy intake from the endogenous feed input coefficients and thereby capture the effects of endogenous changes in the feed mix on digestibility and emissions. Mitigation factors are applied as above, reflecting the saving of methane emissions if anaerobic digestion plants are used, whereas two other technologies included in the GAINS data base (anti-methanogen vaccination and propionate precursors) are not considered in this study.

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

$$where \qquad (5)$$

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

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

Specification of mitigation cost functions

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

For activity levels, the "responsiveness" may be expressed in terms of elasticities, giving the percentage increase in an activity level if the output price, for example, is increasing by 1 %. For mitigation measures responsiveness has been captured in a different way because most observed mitigation shares are zero such that elasticities cannot be defined. Instead responsiveness will be measured in terms of the subsidy, relative to the accounting cost of the mitigation option, that would trigger a full implementation if this relative subsidy were granted only to one option, all else equal, in particular at constant prices. Such a subsidy may be motivated from the existence of a positive carbon price that would be charged to the activity in question, unless emissions are reduced by some fraction. For the cost function calibration we consider the choice of the mitigation share for a single fixed activity where mitigation receives a subsidy S (which is zero in the observed situation). The problem is thus to minimise net cost N:

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

where

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

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

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

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

where

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

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

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

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

$$mshar_{a,m,e} = mshar^1_{a,m,e}.$$

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

$$\partial N^m(mshar^1_{a,m,e}) \big/ \partial mshar^1_{a,m,e} = \kappa_{a,m,e} + \beta_{a,m,e} + \gamma_{a,m,e} \cdot mshar^1_{a,m,e} - s_{a,m,e} \cdot \kappa_{a,m,e} = 0 \tag{9}$$

This is the second condition needed to specify a nonlinear cost function with smooth behaviour of the CAPRI supply models also in the representation of mitigation options.

If the initially observed mitigation share was zero, it may be concluded that there were insufficient unobserved benefits to farmers to render its implementation attractive even for the “early adopters”. In this case it has been assumed that a relative subsidy of $S^1_{a,m,e}$ = 50% of the accounting costs from GAINS $\kappa_{a,m,e}$ would be needed to render the option almost attractive for the first adopter such that the first order condition (8) holds with equality at a zero implementation share. Furthermore, as options with observed zero shares are apparently less attractive to farmers, a full implementation also by “late followers” may only be expected at a higher subsidy rate than 80%. Our assumption was 150% in this case, implying that “late followers” have even unobserved *disutility* from this mitigation option that needs to be overcome to achieve full implementation by all farmers.

Some aspects of this modelling approach have to be stressed.

1) Responsiveness is specified according to plausible assumptions on the results of hypothetical scenarios, the introduction of a specific subsidy for one mitigation option only. This is conceptually not very different from the information in an elasticity matrix, giving the response of some agent if one price is changing and all others constant.
2) The difference to the elasticity case and a weakness of our approach here is the lack of econometric evidence to specify the threshold values for the relative subsidies. However, such evidence is difficult to come by when considering future mitigation options.
3) The approach may have a weak empirical basis, but the alternative to set all unobserved parameters to zero is known to be further away from reality. It would imply, for example, that farmers are homogeneous in a region and would happily switch from one economic option to the next if the latter increases regional income by one Euro. Such jumpiness contradicts all evidence and the modelling philosophy of CAPRI.
4) In this first specification it has not been tried to tailor the trigger values to the mitigation options. It has been considered, for example, to set the relative subsidies higher for “precision farming” than for “nitrification inhibitors” because the share of capital costs (including human) is higher in the former. But transparency suggested to stick to uniform rules depending on whether the observed unit costs and implementation shares were positive or non-positive. This decision also implies that the response of mitigation options to increased relative subsidies is very similar in each of these cases.

3.3 Description and underlying assumptions of the technological GHG mitigation measures considered

A key contribution in the framework of the EcAMPA project is the implementation of some specific endogenous GHG mitigation technologies to the CAPRI model. Next, we briefly describe the modelled mitigation technologies and then outline some underlying assumptions for their integration into the CAPRI modelling system. For the selection of the technological mitigation options to be implemented into CAPRI it was decided to rely on the GAINS database as it already provides mitigation technologies and their cost structure and is used also by other services in the European Commission.[6]

Description of the modelled mitigation technologies

The following GHG technological mitigation options have been specifically considered as options that can be voluntarily applied by farmers: (1) farm scale anaerobic digestion; (2) community anaerobic digestion; (3) nitrification inhibitors; (4) timing of fertilization; (5)

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[6] GAINS is short for “Greenhouse Gas and Air Pollution Interactions and Synergies” which is a model describing the evolution of various pollutants and their abatement options developed by the International Institute for Applied Systems Analysis (IIASA), see http://gains.iiasa.ac.at/.

precision farming, and (6) changes in the composition of animals' diet (feed). The model allows the simultaneous use of different technological mitigation options, e.g. nitrification inhibitors, the timing of fertilisation and precision farming can be combined to reduce the N_2O emissions due to fertilizer applications.

Other technological and management based GHG mitigation options were not considered in this study because the technology or necessary information was not identified in the GAINS database, the share of land under a commodity and its technological mitigation potential in the EU is rather negligible (e.g. rice cultivation), the share of the tackled mitigation source in agricultural GHG emissions is very small (agricultural field burning) or the technology is assumed to be not available commercially by 2030 (i.e. not within the projection period of this study). More specifically:

- Reduction in emissions from rice cultivation: Rice cultivation accounted for only 0.6% of total EU-28 agricultural GHG emissions in 2011 (see Chapter 2.3) and the emission reduction potential for the EU via intermittent aeration of continuously flooded fields, alternative hybrids and sulphate amendments is actually very small (Höglund-Isakson et al., 2013). For this reason reductions of emissions from EU rice cultivation are not incorporated in this study.
- Ban on agricultural field burning: Field burning of agricultural residues accounted for emissions of about 0.8 million tonnes of CO_2eq. in 2011, which represents only a share of 0.2% in total agricultural emissions in the EU-28 (see Chapter 2.3). Furthermore, it has to be noted that agricultural field burning is actually forbidden in the EU and most countries do not report CH_4 and N_2O emissions from this source category (EEA database, 2013). Therefore agricultural field burning is generally not modelled in CAPRI.
- Genetic selection or specific genetic improvements aimed at CH_4 reduction from cows and cattle: A general genetic selection for 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 kg meat or milk. Accordingly, intermediate GHG reductions through genetic improvements are very uncertain (Eckard et al., 2010; Cottle et al., 2011; Clark, 2013; Hristov et al., 2013). In GAINS, specific genetic improvements aimed at CH_4 reduction are considered to be available on a cost neutral basis from 2030 onwards (Höglund-Isakson et al., 2013) and are therefore not incorporated into this study.
- Propionate precursors as additive or through genetic engineering in feed plants and vaccination against methanogenic bacteria in livestock rumens: both technologies are currently not available commercially and their wider application is expected only from 2030 onwards (Höglund-Isakson et al., 2013).

Below we first briefly describe the technological mitigation options considered in this study and then explain the underlying assumptions taken for their integration into the CAPRI modelling system. More information on these options can for example be found in Weiske, 2006; Leip et al., 2010; Höglund-Isakson et al., 2013; Hristov et al., 2013; ICF, 2013.

Farm scale anaerobic digestion

Anaerobic digestion is the bacterial fermentation of organic material under controlled conditions in a closed vessel. This mitigation technology is used at farms with a large number of livestock. The manure and slurry is collected in lagoons and tanks and stored under anaerobic (i.e. without air) conditions. The fermentation process produces methane-containing biogas which is stored and can be used to generate electricity, heat and/or vehicle fuel. Other wastes (e.g. from food processing or agricultural by-products) can also be mixed with the manure to increase the yield of the biogas, thus improving the economics of the anaerobic digestion plant. The GHG mitigation in the context of farm scale anaerobic digestion refers to the reduction in GHG emissions of manure (transitioning from a non-digested to a digested system). Capturing biogas and combusting it for energy generation converts CH_4 into CO_2, and hence reduces the GHG emissions of the farm.

Community anaerobic digestion

This technology is identical to farm anaerobic digestion with the exception that the biogas is produced at a smaller scale. The idea is that community anaerobic digesters use food waste collected from multiple sources in the vicinity of the digestion plant. Apart from producing electricity, heat and/or vehicle fuel, another economic benefit of community anaerobic digestion is that it offers an environmentally beneficial and cost effective solution to hauling biodegradable waste to landfill (which is becoming increasingly expensive). Unlike the farm scale anaerobic digestion, which is assumed to be used at large farms, the community anaerobic digestion technology is also available for smaller farms that do not produce enough manure/slurry to operate a farm scale digestion unit in an economical feasible way. However, as transportation costs of manure for long distances is costly (and involves increases in CH_4 and CO_2 emissions), community anaerobic digestion is considered only to be available in countries with intensive pig farming.

Nitrification inhibitors

Soil nitrogen is very dynamic. To slow down its transformation into other forms that result in N losses and have adverse effects on the environment, nitrification inhibitors can be applied. These inhibitors are chemical compounds that delay bacterial oxidation of the ammonium-ion, by depressing over a certain period of time the metabolism of *Nitrosomonas* bacteria. These bacteria are responsible for the transformation of ammonium into nitrate (NO_2). Thus, the objective of using nitrification inhibitors is to control leaching of nitrate by keeping nitrogen in the ammonia form for a longer time, to prevent denitrification of nitrate-N and N_2O emissions from nitrification and denitrification. In doing so, the inhibitors increase the efficiency of the nitrogen applied and at the same time reduce N_2O emissions from mineral fertilisers (Nelson and Huber, 2001; Weiske, 2006; Delgado and Follett, 2010).

Timing of fertilization

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

Precision farming

Precision agriculture is “an information and technology-based crop management system to identify, analyze, 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, with the goal of optimizing returns on inputs while preserving resources. Because this managerial system enables the farmer to, among other things, make a better use of fertilizers and fuel use, it also directly contributes to reducing GHG emissions. Regarding the GHG emissions related to precision farming, only the reduction in N_2O emissions is taken into account in the CAPRI modelling system.

Changes in the composition of animals' diet (feed)

This GHG mitigation option implies that by (optimally) altering the feed mix of ruminant animals, while keeping a required nutritional intake, it is possible to reduce methane emissions produced during the animals' digestive process. This is modelled endogenously in the new CAPRI version, i.e. the possibility is considered to reduce the gross energy intake by changing the feed mix and thereby reducing the methane emissions. Changes in the feed mix respect the net energy demand of the animals, as well as the dry matter intake and the fibre intake.

Underlying assumptions for the integration of the technological mitigation options into the CAPRI modelling system

The assumptions taken for the integration of the technological mitigation options into the CAPRI modelling system are based on information given in individual spreadsheets from the GAINS database. Below we briefly describe the main information in these GAINS spreadsheets used for this study.

Livestock numbers**.** This spreadsheet provides information on the number of animals (in 1000 heads) by country, animal type (e.g., dairy cows or pigs), and the type of housing of animals (e.g., dairy cows housed in stables with either a slurry-based or a straw-based system). We use this spreadsheet to calculate the share of animals of a given type kept in a specific type of housing in the total number of that type of animals (e.g., the share of dairy cows kept in a slurry-based system in the total number of dairy cows). This share, calculated in the baseline, is then held constant in the policy scenarios.

Housing days. This spreadsheet provides information on the number of housing days of an animal type under a housing type (i.e., slurry or straw system).

All sources – unit cost parameters**.** The unit cost parameters are reported for two greenhouse gases: CH4, N2O. Annualized costs are also reported.

CH_4 (N_2O) emissions by control option**.** This spreadsheet contains information on the CH_4 (N_2O) emissions by a mitigation option. Particularly important to understand is the information on the controlled capacities. For example the maximum share of non-dairy cattle with liquid manure management on large farms (> 200 animals) in Austria is 3.2%; these cows are assumed to be eligible feasible for farm-scale anaerobic digestion.[7] The current rate of application of this technology in Austria is 2.9%, which means that 90% (=2.9/3.2) of the assumed maximum technical application of this technology is already adopted. It has to be noted that the emissions reported in the GAINS database do not refer to total manure management emissions from the respective animal categories but only to emissions from the fraction of animals with liquid manure management (i.e., the fraction of the animals which could be of interest for farm-scale anaerobic digestion).

While farm scale anaerobic digestion is the most represented mitigation option for CH_4, community-scale anaerobic digestion is also used. However, transportation of manure for long distances is costly (and comes with an increase in CH_4 and CO_2 emissions). Following the GAINS data base, community anaerobic digestion plants are therefore only available as a mitigation option in countries with intensive pig farming (more than 200 pigs/km^2), i.e. the Netherlands, Denmark, Belgium, and Malta.

Shares of technological options. According to the GAINS database, the technological mitigations options considered in this study will be used already by the production activity in 2030 under ceteris paribus (see annex 1). These shares were taken over in the reference scenario (REF) and they change endogenously in the scenarios.

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[7] Austria has many small farms and therefore only a small fraction of animals qualify for the large farm requirement.

3.4 Spatial trade model for emission permits in agriculture

One of the emission mitigation policy scenarios conducted in this study offers the possibility of emission permit trading (specifically for agriculture). To allow trading emission permits, a spatial trade model has to be applied in CAPRI. The main features of this spatial trade model are described below.[8]

The stylised spatial equilibrium model described here follows the general framework developed by Takayama and Judge (1971) and is specifically tailored to represent regional (spatial) trade in non-CO2 emission permits (for a more detailed description see Pérez Dominguez and Britz, 2010). Starting with a given permit distribution based on a percentage reduction of historical emissions, the regional supply models are solved, generating dual values related to the maximum permissible emissions. This has an effect on production since, for instance, high emitting activities (e.g. intensive cattle production in the Netherlands) are expected to experience a higher loss in income than low emitting activities (e.g. rain-fed cereal production in south Portugal). These changes in supply and feed demand quantities enter the international market and trade model, where price adjustments for agricultural outputs allow for market clearing. At this stage, the permission trade module re-distributes permits from regions with low marginal abatement costs to other regions with high marginal abatement costs, allowing for welfare gains between the regions involved in the permit trading. According to the distributed emission permits, a new maximum of emissions permitted enter the supply models in the next solve, generating a new vector of regional marginal abatement costs which are also dependent on the updated output price. Again, the market model is solved at updated supply and feed demand quantities. Market clearing of agricultural products and of regional emission permits iterate until convergence is achieved, i.e. changes between iterations for both quantities and prices of agricultural products and emission permits fall beyond pre-defined relative thresholds of 0.05%. The solution characterizes a simultaneous equilibrium in EU agricultural permit markets and regional as well as global primary and secondary agricultural product markets.

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[8] The description in this subsection is mostly taken from the CAPRI-ECC report (cf. Pérez Dominguez et al., 2012). Further and more detailed description is given in Pérez Dominguez (2006) and Pérez Dominguez and Britz (2010).

4 Mitigation potential of the technological options

The mitigation potential of the technological options considered in this study is measured by the marginal abatement cost or curve (MAC), which represents the relationship between the reduction of GHG emissions in CO_2 equivalent (CO_2eq) and the cost of the reduction per tonne of CO_2eq. Each point on the MAC curve corresponds to a combination of mitigation technologies, number of animals, intensity of production, and energy content of animal feed that collectively optimise the cost of achieving a given level of CO_2eq emission reduction. The combination of mitigation technologies is endogenously calculated by the CAPRI model for each NUTS2 region.

The CO_2eq emission reduction ranges between 0 and 40 % relative to the reference scenario (REF). Although the 40% upper bound was chosen arbitrarily, it was deemed to be sufficient in the framework of this study and the figures below show that the increase in the MAC beyond that point is very steep and therefore, unlikely to be reached in practice). To derive each MAC curve, this range was divided into 100 subintervals, each of identical length; the model was then run 100 times, each time minimizing the cost of achieving a given level of CO_2eq emission reduction. This procedure has been applied to each NUTS2 region separately, assuming the market changes in a given region due to the CO_2eq emission abatement have no effects on other regions (i.e., only the CAPRI supply module is run).

As there are more than 200 NUTS2 regions in the CAPRI model, we only present results for a selection of the regions in four Member States (MS): Germany, Sweden, Poland and Romania; for each country, we select three regions – with a low, median, and high MAC curve – to show the heterogeneity within a MS. In general, the MAC curves vary considerably not only among MS, but also within a MS (see Figure 19 to Figure 22).

Table 2 presents MACs for the "median" curve of NUTS2 regions in individual EU Member States for the 19% and 28% CO_2eq emissions reduction. The *median* MAC curve is defined to be the curve which lies in the middle of all MAC curves for a Member State.[9]

As expected, the MACs are significantly higher for the 28% than for the 19% reduction. Regions which are facing a MAC above 25 euro/ton in the 19% reduction see their costs more than doubling when moving to a 28% reduction, while regions with lower values see their MAC multiplied by 3 to 10. The relation between emission reduction and MAC is clearly non-linear.

For the same reduction level, the MAC values are also very heterogeneous among the regions, with a region of Austria, *Salzburg*, corresponding to the median MAC curve facing the highest MAC per tonne of CO_2eq (37.0 euro/tonne and 89.7 euro/tonne in the 19% and 28% reduction scenario, respectively), while the MAC for Hungary's Közép-Dunántúl is 0.3 and 14.9 euro/tonne of CO_2eq, in the 19% and 28% reduction scenario, respectively. This heterogeneity is increasing with higher reduction levels.

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[9] For an even number of the curves, we took the higher of the two middle ones to obtain a conservative estimate of the MAC

Table 2: Marginal abatement costs for "Median" NUTS2 Regions in individual EU Member States (Euro/tonne)

	CO2eq emissions reduction (%)	
	19	**28**
Salzburg (Austria)	37.0	89.7
Auvergne (France)	26.0	65.8
Overijssel (Netherlands)	25.0	66.6
Slovenia	20.5	60.6
Norte (Portugal)	20.1	58.1
Sterea Ellada (Greece)	19.2	62.5
Southern and Eastern (Ireland)	18.0	52.3
Lombardia (Italy)	17.9	71.5
Giessen (Germany)	17.7	55.9
Cyprus	17.3	55.6
Denmark	17.2	65.9
Malta	15.9	57.6
Vest (Romania)	14.1	62.1
Luxembourgh	13.7	49.0
Latvia	13.2	42.0
Scotland (United Kingdom)	12.9	36.9
West-Vlaanderen (Belgium)	12.7	48.1
Pohjois-Suomi (Finland)	12.5	39.9
Estonia	7.8	30.0
Andalucia (Spain)	7.3	31.8
Severovýchod (Czech Rep.)	6.0	37.2
Oestra Mellansverige (Sweden)	5.7	32.3
Kujawsko-Pomorskie (Poland)	5.3	34.2
Východné Slovensko (Slovakia)	5.0	43.1
Lithuania	4.9	27.9
Severozapaden (Bulgaria)	0.9	19.7
Közép-Dunántúl (Hungary)	0.3	14.9

Figure 19: Marginal abatement cost curves for selected regions in Germany

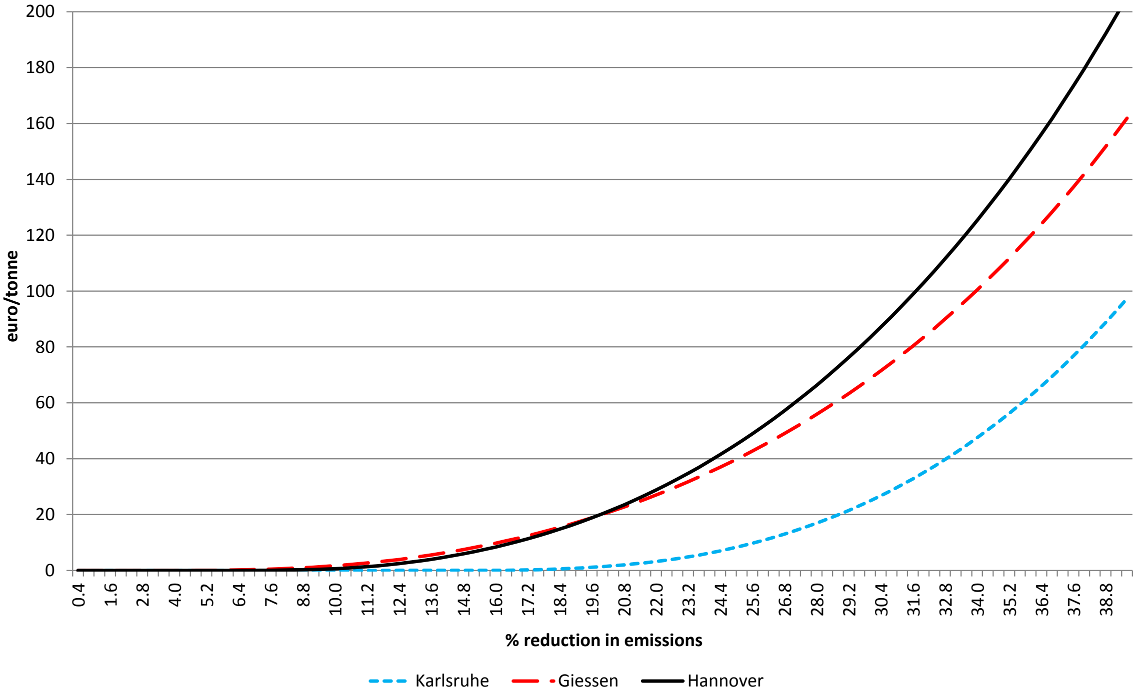


Figure 20: Marginal abatement cost curves for selected regions in Sweden

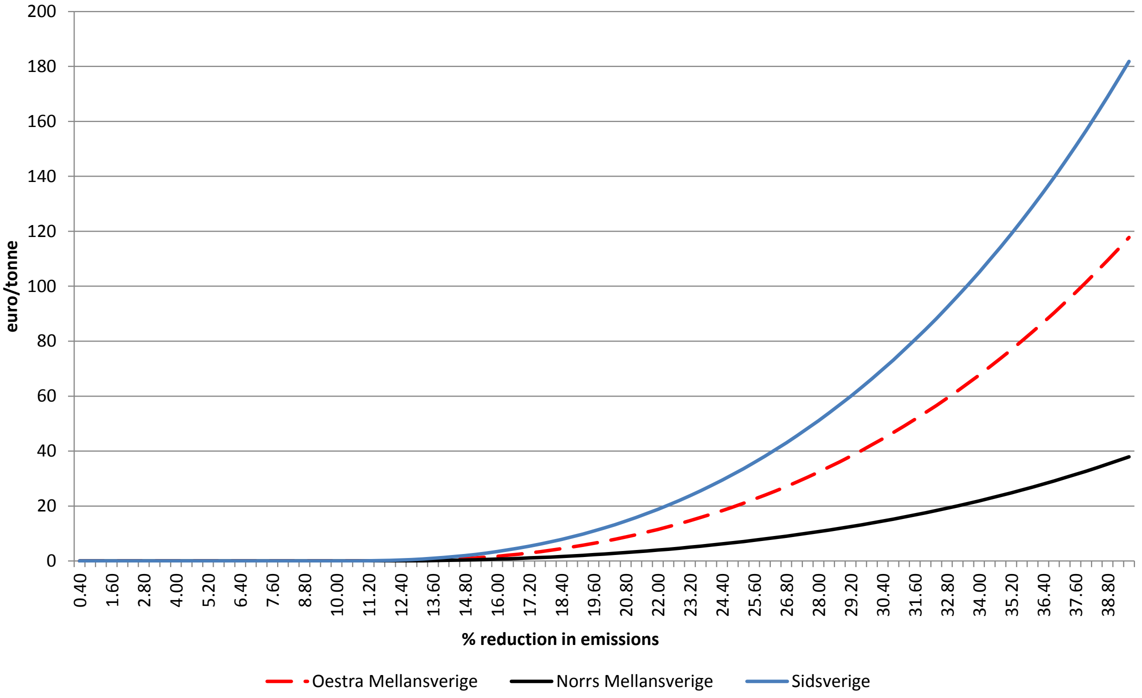


Figure 21: Marginal abatement cost curves for selected regions in Poland

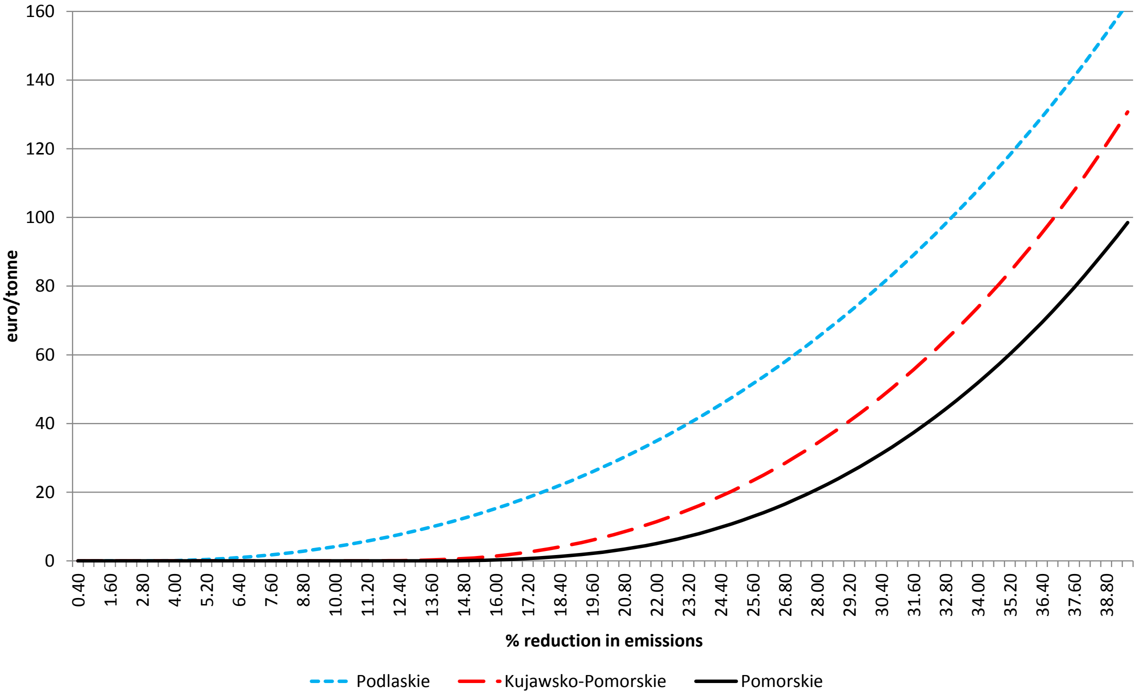
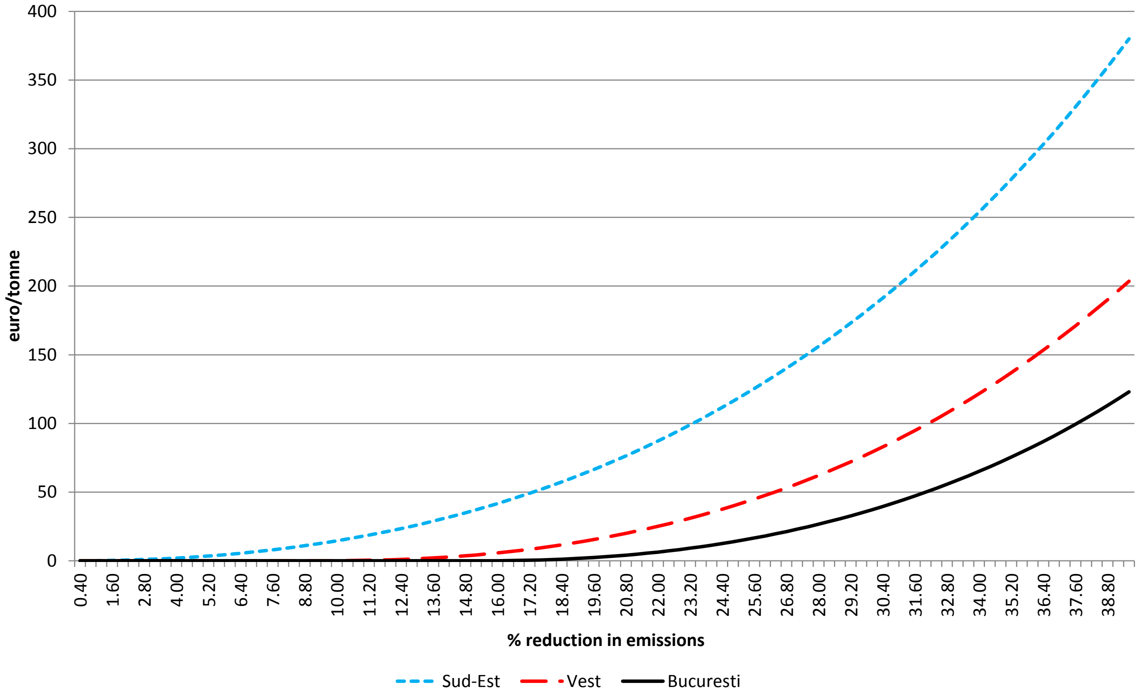


Figure 22: Marginal abatement cost curves for selected regions in Romania



5 Background and definition of the simulation scenarios

One of the main objectives of this study is a quantitative assessment of potential GHG mitigation policy options in the agricultural sector, and their production and economic implications. The principal policy options analysed are mandatory GHG emission reduction targets, allowing for the use of different mitigation technologies for farms. Furthermore, three scenarios with different subsidy levels for the uptake of the technological mitigation options are assessed (however, in these scenarios no mandatory GHG emission reduction targets are set).

Projection year for all scenarios is 2030. The proposed and examined mitigation policy scenarios are intended to explore what could happen if policies would be implemented that explicitly force farmers in the EU-27 to reach GHG emission reductions which are in line with the roadmap for moving to a low-carbon economy in 2050. In line with the Roadmap 2050 it can be expected that reduction of emissions from agriculture for the EU-28 as a whole could be in the range of 19% to 28% by 2030 compared to 2005 to meet a reduction in EU GHG emissions of 30% (40%) in 2030 compared to 1990 (cf. European Commission, 2014b, p.57). Thus the simulated overall reduction targets for agriculture are based on the impact assessment of the 2030 framework and give indications on the order of magnitude of the reductions that might be needed in 2030 in agricultural non-CO_2 GHG emissions as part of various options to meet a reduction in GHG emissions in the context of a climate policy for 2030.[10] Nonetheless, it has to be highlighted that the policy scenarios are purely theoretical and hypothetical as no decision has been made of the climate and energy policy framework for 2030 in the EU and the scenarios therefore do not reflect policy measures that are already agreed on or are under formal discussion.

This chapter deals with the building and definition of the GHG mitigation scenarios, first presenting a brief overview on all proposed simulation scenarios (section 5.1) and then describing the scenarios and underlying assumptions in more detail (section 5.2).

5.1 Scenario overview

To assess the possible future evolution of agricultural GHG emissions in the EU several scenarios were constructed. First, a reference scenario (REF) is constructed and examined. It is important to mention that the reference scenario in this project is different from the ‘standard’ CAPRI baseline. The Baseline (BAS) is calibrated to results of the AGLINK-COSIMO model 2012, which takes into account the most likely developments of agricultural markets, including the Common Agricultural Policy (CAP) as it is known at that stage. Thus, the scenarios do not include the measures of the CAP Reform 2014-2020, as they were still unclear at the start of this study and the exact implementation of some of the measures at MS level were still not decided when the study was conducted. The Baseline serves as a comparison point in the year 2030 for the analysis of the reference scenario (REF), which is similar to the baseline but considers specific technological mitigation technologies that farmers can voluntarily apply. National abatement measures for non-CO_2 GHG emissions

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[10] For more information see the Communication of the European Commission on "A policy framework for climate and energy in the period from 2020 up to 2030" (European Commission, 2014a) and the accompanying impact assessment (European Commission, 2014b).

from agriculture are not explicitly taken into account, but limited GHG mitigation occurs based on existing EU or national (environmental) legislation. Furthermore, the reference scenario considers non-zero implementation of certain mitigation technologies based on the GAINS database (2013).

The first step of the CAPRI baseline process mainly relies on an analysis of historical trends and on expert information for particular markets (e.g. specific regional market developments). The CAPRI baseline used in this project relies on the 2012 version of the DG AGRI baseline (European Commission, 2012), which gives medium-term projections for 2012-2022 by applying an adjusted version of the AGLINK-COSIMO model used for the OECD-FAO agricultural outlook (OECD-FAO, 2012). As the projection year in this project is 2030, the projection results of OECD-FAO (2012) had to be extended up to the year 2030. The variables considered within the calibration process are: supply, demand (food, feed, biofuels and other use), production, yields and prices. The EU baseline considered includes recent assumptions on macroeconomic drivers (GDP, population, oil price) and the evolution of the CAP. However, the regional resolution of the AGLINK-COSIMO baseline in the EU is limited to the aggregates of EU-15 and EU-N12. Therefore, the CAPRI baseline needs to disaggregate this information at MS and regional level. Trends and expert information from various sources together are almost sure to be inconsistent in some aspect and to violate basic technical constraints such as adding up of crop areas or balances on young animals. As a consequence all expert information is usually provided in the form of target values. Deviations from them are penalised within the statistical calibration framework in CAPRI if necessary.

The second step of the CAPRI baseline process supplements the consistent price-quantity framework with a detailed policy specification. EU agricultural trade policy measures are governed by the Uruguay Round Agreement on Agriculture (URAA) and no assumptions are made concerning bilateral trade agreements currently under negotiation. The policy assumptions complete the definition of the CAPRI baseline and they determine via the parameter calibration the starting point for the subsequent scenario analysis. However, the quantitative projections for the baseline year 2030 are more crucially determined from step one, the baseline process and thus from the integration of trends, expert information, and technical constraints.

Reference and mitigation policy scenarios

For this project specific technological mitigation technologies that farmers can voluntarily apply are considered in the Reference Scenario (REF) and also in the GHG mitigation policy scenarios. The mitigation policy scenarios examined in this report aim at a compulsory GHG emission reduction target of, depending on the specific scenario, -19% or -28% in the year 2030 compared to EU-27 emissions in the year 2005. Furthermore, in a set of three subsidy scenarios without specific emission mitigation targets, we examine the effects of different subsidy levels for the implementation of technological mitigation measures. An overview on the scenarios for a detailed analysis is given in Table 3.

Table 3: Overview on the reference and mitigation policy scenarios

Acronym	Scenario Name	Policy Instrument
REF	Reference Scenario	No specific policy measures implemented that explicitly aim at GHG emission abatement in agriculture
HOM19	Homogenous Emission Reduction by 19% Scenario	Reduction of emissions with a regionally homogeneous cap of 19% and 28 % (no trade in emission rights)
HOM28	Homogenous Emission Reduction by 28% Scenario	
HOM19ET	Homogenous Emission Reduction by 19% Scenario with emission permits trading	Reduction of emissions with a regionally homogeneous cap of 19% and 28%, trade in emission rights across EU
HOM28ET	Homogenous Emission Reduction by 28% Scenario with emission permits trading	
HET19	Heterogeneous Emission Reduction by 19% Scenario	Reduction of emissions with emission caps per MS based on the distribution key of the EU effort sharing agreement (no trade in emission rights), Reduction targets for the EU-27 are 19% and 28%
HET28	Heterogeneous Emission Reduction by 28% Scenario	
SUBS30	30% Subsidy to Mitigation Technologies	Subsidy scheme of 30%, 60% and 90% to the unit cost of mitigation technology without a predefined emission reduction target
SUBS60	60% Subsidy to Mitigation Technologies	
SUBS90	90% Subsidy to Mitigation Technologies	

Note: all scenarios consider specific technological mitigation options that farmers can voluntarily apply.

As farms in the EU are already subject to detailed reporting obligations in terms of nutrition loads (e.g. use of mineral fertilizer) and activity numbers (e.g. number of cows), it is assumed that the mitigation policies do generally not involve additional transaction costs for the government (for administering, monitoring) or the farmers (for documenting). An exception is made for the scenarios with emission permit trading, where additional transaction costs are explicitly considered, covering fixed costs arising from setting up and maintaining the emission trading system as well as variable costs related to initiating and completing transactions (e.g. finding partners, consulting with experts) (see further down below in Section 5.2.4).

5.2 Definition of the reference and mitigation policy scenarios

In this section we describe the assumptions underlying the reference and mitigation policy scenarios in more detail.

5.2.1 Reference Scenario (REF)

The construction of a reference scenario combines the baseline trends with the availability of non-mandatory GHG mitigation technologies. The reference scenario serves as a comparison point for the policy simulations and is meant to provide a consistent view on the likely evolution of the agricultural markets over the projection period under a specific set of assumptions about exogenous drivers. Hence the reference scenario provides a projection in time that does not intend to constitute a forecast of what the future will be, but represents a description of what may happen under a specific set of assumptions and circumstances, which at the time of projections were judged plausible (cf. Blanco Fonseca 2010, iMAP modelling team, 2011).

The REF scenario for this study assumes status quo policy scheduled in the current legislation, based on the information available at the end of August 2013. The changes in legislation adopted since that date have not been taken into account, e.g. the CAP Reform 2014-2020 measures are not considered in the presented scenarios. Although the agricultural sector is included in the GHG emission reduction obligation of the so-called climate and energy package of 2009, no mandatory measures are considered for GHG emission abatement in the reference scenario[11]. On the other hand, the technological GHG mitigation measures described in Section 3.3 are already available to the farmers in the REF. The exact levels of the uptake of each technological mitigation measure are taken from the GAINS database and can be found in annex 1. If no data was available for a country, the assumption is that the uptake in 2030 is zero.

Table 4: Summary of assumptions and scenario characteristics: Reference Scenario

	REF
GHG abatement policy	No specific policy measures implemented that explicitly aim at GHG emission abatement in the agricultural sector. Limited mitigation occurs based on existing EU or national (environmental) legislation.
Projection year	2030
GHG abatement	GHG abatement technologies are applied at the level indicated in the GAINS database (non-mandatory, assumed as a natural up-take of technologies)

5.2.2 Homogenous Emission Reduction Scenarios (HOM19) and (HOM28)

Command and control (CAC) policy instruments are the most commonly used instruments to address environmental negative externalities such as urban air pollution, nitrogen leaching or CH_4 emissions. CAC regulation commonly uses the setting of standards, i.e. a mandated level of performance that is enforced by law. There are different types of standards that could be applied on agriculture in order to reduce GHG emissions[12]; in this study we focus on emission standards that put a cap on the level of GHG emissions. It should be noted that restrictions on GHG emissions have not been directly implemented yet in EU agriculture, but indirectly through for example restrictions on the rate of fertilizations within nitrates vulnerable zones (within the nitrate directive). In line with the Roadmap 2050 it can be expected that reduction of emissions from agriculture for the EU-28 as a whole could be in the range of 19% to 28% by 2030 compared to 2005 to meet a reduction in EU GHG emissions of 30% (40%) in 2030 compared to 1990 (cf. European Commission, 2014b, p.57).

In the homogenous emission reduction scenarios a regionally homogeneous cap is set for GHG emissions from agriculture in the EU-27. The level of GHG emissions will be reduced by

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[11] While MS actually have binding GHG emission abatement targets that also include agriculture, there are so far no explicit policy measures, except in some MS, implemented that would specifically force GHG emission abatement in the agricultural sector. Consequently, no explicit policy measures for GHG emission abatement are considered in this reference scenario.

[12] Basically there are three types of standards: ambient standards, emission standards and technology standards.

19% (28%) in the year 2030 compared to emissions in 2005. The emission reduction targets are equally applied across all regions at Nuts 2 level (thus independent from regional differences in emission abatement costs) and are assumed to be binding in the year 2030 on top of the legislation lined out in the reference scenario. This homogenous reduction for each region does not reflect current climate policy for the agricultural sector nor any of the options for agriculture that has been considered in the 2030 framework. These scenarios could be considered as a very rigid implementation of a reduction of GHG emissions and results might be interpreted as an 'upper limit' of the potential impact.

Table 5: Summary of assumptions and characteristics: Homogenous Emission Reduction by 19% Scenario

	HOM19 and HOM 28
GHG abatement policy	Homogenous emission restrictions in EU-27 regions and farming systems (emission cap equally applied)
Projection year	2030
GHG abatement	19% (HOM19) and 28% (HOM28) reduction compared to 2005 Methane and nitrous oxide emissions covered (aggregated to CO_2 equivalents by using IPCC global warming potentials)

5.2.3 Heterogeneous Emission Reduction Scenarios (HET19 and HET28)

These emission reduction scenarios describe a redistribution of a 19% and a 28% GHG emission reduction commitment in EU-27 agriculture between the years 2005 and 2030 across MS, according to a distribution that is based on the “Effort Sharing Decision” (ESD) (c.f. Decision No 406/2009/EC, adopted jointly by the European Parliament and the Council). According to the ESD, the overall GHG emission reduction objective is distributed across MS, corresponding to a non-uniform GHG emission standard. Thus, under the ESD some MS (e.g. Germany) have to reduce GHG emissions by a certain level, while other MS (e.g. Romania) are potentially allowed to even increase their emissions up to a defined level (cf. Table 6) This effort sharing mechanism was allowed by the Kyoto Protocol to parties acting jointly such as the EU. It has to be acknowledged that there is no ESD for 2030 yet and therefore this scenario represents only a hypothetical situation with the current ESD as a rough theoretical reference point.

For the HET19 and HET28 scenarios the distribution key of the ESD is taken as a starting point for an uneven distribution of GHG emission limits at MS level. These limits at MS level are adjusted according to a linear modification, such that a 19% (28%) emission reduction is achieved for the EU-27 (cf. Table 7).

Table 6: MS GHG emission reduction commitments in 2020 compared to 2005 emission levels according to the ESD

Member State	GHG emission limits (%)	Member State	GHG emission limits (%)
Austria	-16.0		
Belgium-Lux.	-15.0		
Denmark	-20.0	Bulgaria	20.0
Finland	-16.0	Cyprus	-5.0
France	-14.0	Czech Republic	9.0
Germany	-14.0	Estonia	11.0
Greece	-4.0	Hungary	10.0
Ireland	-20.0	Latvia	17.0
Italy	-13.0	Lithuania	15.0
Netherlands	-16.0	Malta	5.0
Portugal	1.0	Poland	14.0
Spain	-10.0	Romania	19.0
Sweden	-17.0	Slovak Republic	13.0
United Kingdom	-16.0	Slovenia	4.0

Source: Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.

Table 7: MS GHG emission reduction commitments in 2030 compared to 2005 emission levels assumed in the in HET19 and HET28 scenarios

Member State	GHG emission limits		Member State	GHG emission limits	
	HET19 (ESD+9%)	HET28 (ESD+19%)		HET19 (ESD+9%)	HET28 (ESD+19%)
Austria	-25	-35			
Belgium_Lux.	-24	-34			
Denmark	-29	-39	Bulgaria	11	1
Finland	-25	-35	Cyprus	-14	-24
France	-23	-33	Czech Republic	0	-10
Germany	-23	-33	Estonia	2	-8
Greece	-13	-23	Hungary	1	-9
Ireland	-29	-39	Latvia	8	-2
Italy	-22	-32	Lithuania	6	-4
Netherlands	-25	-35	Malta	-4	-14
Portugal	-8	-18	Poland	5	-5
Spain	-19	-29	Romania	10	0
Sweden	-26	-36	Slovak Republic	4	-6
United Kingdom	-25	-35	Slovenia	-5	-15

It has to be noted that this scenario effectively assumes that the agricultural sector is taken out of the existing ESD, so that the current ESD targets remain for the non-agricultural sectors and new targets are created for agriculture alone, as to match an overall reduction of agricultural emissions in the EU-27 against 2005. The rationale behind this scenario is to model an uneven distribution of MS targets; however these targets do not reflect current policy, i.e. for the sake of this modelling exercise the distribution key of the ESD is taken as the only existing approximation of such an uneven distribution. The targets are defined at the MS level (cf. Table 7 above) and are homogeneously applied to all regional production systems within the respective MS.

Table 8: Summary of assumptions and characteristics: Heterogeneous Emission Reduction Scenarios

	HET19 and HET28
GHG abatement policy	Emission standard with heterogeneous emission restrictions in EU-27 regions and farming systems (emission caps according to a specific effort sharing agreement for agriculture)
Projection year	2030
GHG abatement	19% (HET19) and 28% (HET28) reduction compared to 2005 Methane and nitrous oxide emissions covered (aggregated to CO_2 equivalents by using IPCC global warming potentials)

5.2.4 Homogenous Emission Reduction Scenarios with Emission Permits Trading (HOM19ET and HOM28ET)

In an Emission Trading System (ETS) GHG emissions of all participants are limited and target amounts (emission caps) are decided on, usually amounting to less emission than encountered at present (depending on the agreed emission target, which in rare cases also allows increase in emission). According to the allocation procedure participants are assigned a certain amount of emission rights (permits) for a specified time period. The participants can then either make use of the rights to emit GHGs or they can trade permits with other participants. In October 2003 the EU adopted a proposal for a directive on CO_2 emission trading to be operable by January 2005 (Council of the European Union, 2003), establishing a coordinated EU Emission Trading System (EU ETS) over all MS within the EU. To date, the EU ETS is only applied to industrial and energy producing activities, but other sectors might be included in the future with a view to further improving the economic efficiency of the scheme through possible amendments (European Council, 2009).[13]

In the Homogenous Emission Reduction Scenarios with Emission Permits Trading (HOM19ET and HOM28ET), we assume the implementation of a specific Emission Trading Scheme only for Agriculture (ETSA) in the EU-27[14]. The ETSA is meant to implement a European market of agricultural GHG emission permits affecting all agricultural production activities (i.e. livestock and crop activities are both included in this ETSA). Transaction cost (TC) for implementing

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[13] For actual information on the EU Emissions Trading System please refer to the respective website of the Directorate-General for Climate Action (DG CLIMA): http://ec.europa.eu/clima/policies/ets/

[14] In this hypothetical scenario, the inclusion of the agricultural sector in an agricultural specific ETS should also require its exclusion from the ESD.

and maintaining the ETSA are explicitly considered, taking into account information on TC related to existing emission trading schemes.[15] For the ETSA scenarios, variable and fix transaction costs are considered, both with the effect of increasing marginal abatement costs (MAC). Variable TC comprise mainly brokerage fees and finding partners and are paid by permit buyers. In the ETSA scenarios TC are assumed to vary around 5 % of the transaction value (c.f. Eckermann et al. 2003, p. 16). For the selection of the 'appropriate' TC value in relation to the final permit price, a 'sensitivity analysis' for different values was carried out with the CAPRI model. Moreover, institutional costs of the trading scheme (approximately 50 Million Euro) are assumed as fix costs for setting up and maintaining the agricultural emission trading market. These fix costs are also assumed to be paid by permit buyers and therefore distributed over transactions. It has to be noted that the assumptions on the fixed costs are not based on empirical evidence of existing permit trading schemes but on information found in the literature for the Clean Development Mechanism (CDM) and Joint Implementation (JI) projects (cf. Eckermann et al. 2003, pp. 6 8). In addition it could be argued that the assumed fixed costs would potentially be lower if the agricultural trading scheme would somehow rely on the (technical) infrastructure provided by the existing EU ETS. Nonetheless, setting up and maintaining a specific emission trading scheme for agriculture undoubtedly would surely involve a certain amount of (fixed) costs. While part of these costs could be covered by governments, a certain amount for setting up and maintaining the scheme at farm level would remain.

In order to test the effect of TC to the performance of the ETSA scenario, different levels of TC have been subject to a sensitivity analysis. Regarding TC it has to be further noted that in the modelled ETSA farmers would be directly trading emission permits with each other but not with other sectors (i.e. an isolated market only for agriculture is assumed). In our modelling exercise, TC are defined per emission permit and include also monitoring/verification costs as part of the fix costs. As farms in the EU are already subject to large reporting obligations in terms of nutrient loads and activity numbers, we assume that additional transaction costs for the farmers through a hypothetical stock market for agricultural GHG emissions could be kept at reasonable levels. However, when looking at the TC, also the presence of scale economies in the management of tradable permits should actually be kept in mind. As pointed out in the literature, overall transaction costs may also vary with the size of the transactions per firm (i.e. in our case farm), with TC being higher for smaller firms (see e.g. Heindl, 2012). This implies that marginal TC in an emission trading scheme also depend on the size of the firm (or more precisely on the amount of tradable emission permits it possesses), an effect that is not specifically covered in our analysis. In addition, with regard to cost savings of emission trading schemes, the literature points out that potential cost savings of emission trading can be significantly diminished by speculative behaviour, imperfect foresight, market power, etc. (see e.g. Claasen et al., 2005).

We are aware that the assumptions we make in our study regarding transaction costs of a specific emission trading scheme for agriculture are rough. However, empirical evidence shows that firms take the TC involved in the management of tradable emission permits into account and consequently the firm's incentives to mitigate GHG emissions are different than

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[15] Transaction costs as defined in this scenario are those costs that arise from setting up and maintaining the emission trading system, initiating and completing transactions, such as finding partners, holding negotiations, consulting with lawyers or other experts, etc.

in the theoretical case without TC (see e.g. Heindl, 2012 on TC in the EU ETS). Therefore we think it is better to assume a certain kind of TC than just entirely ignoring them. Nonetheless it has to be stressed again that the available information on transaction costs with respect to the emission trading scheme is scarce, thus no robust conclusions can be derived from this exercise regarding the real transaction costs of a specific emission trading scheme for agriculture.

In line with the other mitigation policy scenarios, in this modelling exercise of an ETSA the target is to achieve a 19% (HOM19ET) and 28% (HOM28ET) agricultural GHG emission reduction in 2030 compared to 2005. Therefore, in the same way as in the HOM19 and HOM28 scenarios a regionally homogeneous emission cap (-19% and -28% respectively) is set on agricultural GHG emissions in all EU Nuts 2 regions. The difference to the HOM scenarios is that now, according to the cap and historical emission levels, tradable emission permits are allocated to agricultural producers (1 permit equals 1 tonne of CO_2 equivalent, where CH_4 and N_2O emissions from agricultural sources are considered). The agricultural producers can decide to use the permits in order to emit GHG or they can trade them with other agricultural producers. As the emission reduction target is enforced for the aggregate of all EU-27 in this ETSA scenario, trade of emission permits is allowed between regions (i.e. Nuts 2 level) within MS and at EU-27 wide level. Thus, for example regions specialised in livestock production are allowed to trade with regions specialised in arable production. The direction of permit trade will depend on the emission-intensity of the farmers' respective production-mix and the corresponding burden imposed by the selected policy instrument.

Table 9: Summary of assumptions and characteristics: Homogenous Emission Reduction with Emission Permit Trading Scenarios

	HOM19ET and HOM28ET
GHG abatement policy	Homogenous emission restrictions in EU-27 regions and farming systems (emission cap equally applied) with trade in emission rights between EU Member States and regions
Projection year	2030
GHG abatement	19% (HOM19ET) and 28% (HOM28ET) reduction compared to 2005 Methane and nitrous oxide emissions covered (aggregated to CO_2 equivalents by using IPCC global warming potentials)

5.2.5 Mitigation technology subsidy scenarios (SUBS30, SUBS60, SUBS90)

In this set of scenarios, a voluntary support scheme is mimicked that gives the farmers a subsidy if they use (one or more of) the modelled GHG mitigation technologies. The support scheme introduces a relative subsidy of respectively 30%, 60% and 90% applied to the unit cost (or benefit) of all modelled mitigation technologies. Contrary to the previous scenarios, no emission reduction targets are defined. Since no targets are specified, these subsidy scenarios are very close to the hypothetical scenarios used for model calibration as described in Section 3.2 and the current implementation of certain agro-environmental schemes under pilar 2 of the CAP.

The main difference is that all options are simultaneously receiving subsidies. As their implementation shares have to add up to one by activity, there may be competition between different subsidised options. For example, the (four) fertiliser related mitigation options or “community based” and “farm based” AD plants. Another difference is that activity levels may be increased in case their profitability is increased by the subsidy.

Table 10: Summary of assumptions and characteristics: Mitigation Technology Subsidy Scenarios

	SUBS30, SUBS60, SUBS90
GHG abatement policy	Relative subsidy of 30%, 60% or 90% to the unit cost of each mitigation technology in all EU-27 regions
Projection year	2030
GHG abatement	No predefined emission reduction target

6 Scenario results

6.1 Changes in agricultural GHG emissions per EU Member State

Table 11 presents a decomposition of the overall agricultural GHG emissions developments under various scenarios. The technological GHG mitigation options described in chapter 2 are available in all scenarios. The reference scenario (REF) indicates the development of GHG emissions with no specific emission reduction requirements for agriculture in place, and shows the relative difference in emission levels between the projection year 2030 and the base year 2005. The other scenarios show the policy effect of implementing the respective GHG reduction obligation by depicting the relative change compared to the reference scenario in the year 2030.

In REF, no specific GHG reduction requirements are implemented but the technological mitigation options are available and farmers can voluntarily use them. Thus, the GHG emissions in 2030 of the reference scenario are a result of general market developments and in some cases the voluntary application of technological mitigation options (as some farmers might apply them if they result in positive income effects). Table 11 shows an overall reduction in agricultural GHG emissions for the EU-27 of 0.2% in the year 2030 compared to the year 2005. However, the projection results are quite diverse between the MS, and while 10 MS show a decrease in emissions, the others are projected to have an increase. In the EU-15, results show a decrease of 0.6%, with highest reductions being projected for Greece (-11.6%), Italy (-4.8%) and France (-4.2), whereas eight EU-15 MS show an increase in emissions, with the highest increases indicated for Portugal (+15.8%), Austria (+8.7%)and Spain (+7.1%). For the EU-N12 an increase of 1.2% is projected, with eight countries increasing their emissions (some countries quite remarkably). Most pronounced increases are predicted for Bulgaria and Latvia (+20.4% and 20.3%, respectively) and highest decreases for Romania and Hungary (-11.2% and -4.9%, respectively).

In the mitigation policy scenarios we simulate EU-27 wide GHG emission reduction obligations. The emission reduction obligations are set per MS or NUTS2 region by implementing emission standards (caps), i.e. each MS or NUTS2 region is required to reduce its agricultural GHG emissions by a certain amount compared to the year 2005. We model three different ways of setting MS reduction targets, reflecting a homogenous (with and without trade in emission permits) and a heterogeneous distribution of emission caps. In line with their scenario acronym the overall GHG emission reduction target at EU-27 level in the scenarios is 19% and 28% respectively (cf. chapter 5).

In the scenarios entitled HOM19 and HOM28 we implement a homogeneous minimum GHG reduction target of 19% and 28% respectively for every MS, which by construction aims to achieve also a reduction of 19% and 28% at the EU-27 level. In the scenarios HOM19ET and HOM28ET there is also a homogeneous minimum GHG reduction target of 19% (28%) implemented for every MS, but agricultural producers receive emission permits that can either be used to emit GHG gases or to be traded with other agricultural producers. Emission permits trading is allowed with other NUTS-2 regions at both MS and EU-27 level, and therefore agricultural GHG emissions in the projection year 2030 can vary from the homogenous initial cap introduced for MS (but the overall emission reduction target still has to be met at EU-27 level). In the scenarios entitled HET19 and HET28, we simulate emission abatement obligations that are heterogeneous across MS, with the distribution key of emission caps for MS being based on the EU effort sharing decision. The overall GHG reduction targets for the EU-27 are also 19% and 28% respectively. In all policy scenarios a small deviation from the emission reduction targets was tolerated because of the computational complexity of exactly meeting the required reductions.

The changes in GHG emissions per EU MS according to each policy scenario are presented in Table 11. As we are interested in separating the policy effect from the effects without a specific emission reduction policy in place, results are presented relative to the reference scenario. Accordingly, looking for example at Germany in the HOM19 scenario, it can be seen that from the emission reduction obligation of 19% Germany already achieved a reduction of 2.2 percentage points in the reference scenario, hence the reduction of 17.6 percentage points is policy induced and achieved by a combination of both further changes in the agricultural sector (e.g., reduction in herd sizes or crop area) and further applications of technological mitigation options.

The emission reductions presented in Table 11 are pretty much straightforward in the scenarios with the homogenous reduction commitments without tradable emission permits (HOM19 and HOM28) as the scenarios could be modelled in a way that the respective 19% and 28% emission reduction obligations compared to the year 2005 are met at EU-27 and also at Member State level. However, regarding the policy scenarios with heterogeneous reduction commitments (HET19 and HET28), the commitments of some EU-N12 MS imply that they could actually increase their emissions compared to the year 2005. The modelling effect in CAPRI is that, depending on the number of iterations, the bounds around the reduction objectives can vary the result for the overall emission reduction in the EU-27. This variation is due to the fact that other constraints, related to agricultural production and not to emission reduction targets, prevent some of the MS from fully using the emission possibilities they are actually allowed to (this effect is e.g. particularly pronounced in Romania). In order to get hold of the variation we had to concentrate in the modelling on the achievement of the overall emission reduction target at EU-27 level. As a result of this variation in the EU-N12, the envisaged emission reduction objectives are surpassed in both HET scenarios at EU-27 level, with reductions of 19.5% and 28.8% respectively.

The emission reductions in the scenarios with the homogenous reduction commitments and tradable emission permits (HOM19ET and HOM28ET) can best be interpreted if directly compared to the scenario results of the scenarios with the homogenous reduction commitments but without tradable emission permits (HOM19 and HOM28). For example, comparing HOM19ET with HOM19 it can be seen that at EU-27 level, 16 MS show lower net emission reductions in the scenario with emission permits trading, indicating that these MS are net buyers of emission permits, i.e. in these MS it was more beneficial to buy emission permits instead of reducing GHG emissions by as much as initially obliged to by the homogenous cap. This effect is actually shown in nine EU-15 MS, with e.g. Portugal’s emissions 11 and Austria’s emissions 10.3 percentage points higher in HOM19ET compared to HOM19. On the contrary, five EU-15 MS are net sellers of emission permits and hence reduce their emissions more in HOM19ET compared to HOM19; e.g. emissions in the UK and Ireland decrease by a further 11.6 and 3.8 percentage points respectively. In the EU-N12, agricultural GHG emissions are 0.6 percentage points higher in HOM19ET than in HOM19, indicating that the aggregated EU-N12 is a net buyer of emission permits. Nine EU-N12 MS are actually net buyers of emission permits, especially Malta and Cyprus which reduce emissions by respectively 17.2 and 12.3 percentage points less in HOM19ET compared to

HOM19. On the other hand, three EU-N12 MS are net sellers of emission permits, with emissions in Romania, Estonia and Hungary decreasing by a further 10.8, 6.0 and 4.1 percentage points respectively in HOM19ET compared to HOM19.

Table 11: Changes in agricultural GHG emissions per EU Member State in 2030 according to each scenario

	2005	REF	HOM19	HOM28	HOM19ET	HOM28ET	HET19	HET28	SUB30	SUB60	SUB90
	[1000t]	% difference to 2005	% difference to REF								
EU-27	400,965	-0.2	-19.1	-28.1	-19.1	-28.1	-19.3	-28.6	-0.6	-2.0	-4.5
Austria	7,461	8.7	-25.8	-34.1	-15.5	-23.0	-31.3	-40.6	0.0	-1.1	-3.2
Belgium-Lux	9,354	2.1	-20.8	-29.4	-16.4	-22.9	-25.6	-35.3	-2.6	-4.2	-6.1
Denmark	9,747	-0.9	-17.6	-26.6	-14.5	-19.1	-27.7	-37.9	-2.9	-3.8	-5.5
Finland	7,284	5.9	-23.8	-32.4	-27.3	-40.4	-29.5	-39.0	0.0	-1.0	-2.9
France	74,366	-4.2	-15.8	-25.2	-16.4	-24.7	-20.0	-30.4	-0.5	-1.9	-4.6
Germany	61,139	-2.2	-17.6	-26.8	-17.1	-24.9	-21.7	-32.0	-0.5	-1.9	-4.6
Greece	5,945	-11.6	-8.9	-18.9	-12.7	-18.5	-2.6	-13.3	-0.2	-1.5	-3.8
Ireland	21,298	4.5	-22.7	-31.3	-26.5	-42.0	-32.2	-41.9	-0.4	-1.2	-2.8
Italy	28,216	-4.8	-15.3	-24.8	-9.9	-13.1	-18.5	-29.0	-0.7	-2.2	-3.7
Netherlands	17,216	5.8	-22.9	-31.5	-15.2	-22.7	-28.6	-38.1	-1.5	-2.4	-4.4
Portugal	5,048	15.8	-30.4	-38.1	-19.3	-28.7	-21.0	-29.5	-0.3	-1.1	-2.3
Spain	31,009	7.1	-24.7	-33.1	-22.8	-33.8	-24.7	-34.0	-0.9	-2.8	-4.8
Sweden	6,909	4.1	-22.3	-31.0	-17.4	-25.5	-29.0	-38.7	-0.2	-1.2	-3.3
UK	45,654	-3.7	-16.3	-25.6	-27.9	-44.0	-22.5	-32.9	-0.1	-1.1	-3.0
EU-15	330,647	-0.6	-18.8	-27.9	-19.0	-28.4	-23.1	-33.2	-0.7	-1.9	-4.1
Bulgaria	3,969	20.4	-32.4	-39.9	-22.3	-28.9	-7.4	-15.8	0.0	-3.3	-9.9
Cyprus	397	7.2	-24.3	-32.7	-12.0	-15.6	-19.7	-29.0	-1.6	-3.9	-5.3
Czech Republic	6,096	3.8	-23.1	-31.5	-20.7	-25.6	-4.9	-14.6	-0.1	-2.6	-7.2
Estonia	1,232	5.0	-23.1	-31.6	-29.1	-44.6	-3.2	-12.7	-0.1	-1.6	-4.4
Hungary	7,249	-4.9	-15.3	-24.7	-19.4	-24.1	3.6	-4.8	-0.1	-3.4	-9.5
Latvia	1,799	20.3	-34.0	-41.2	-24.8	-40.9	-12.0	-20.1	0.0	-1.1	-3.2
Lithuania	3,681	12.7	-29.5	-37.4	-23.8	-35.1	-7.5	-16.3	0.0	-2.0	-5.8
Malta	67	12.4	-27.9	-35.9	-10.6	-13.4	-14.6	-23.5	-1.3	-3.6	-5.5
Poland	27,185	3.7	-22.1	-30.8	-18.4	-25.5	-1.5	-8.7	0.0	-1.9	-5.4
Romania	14,995	-11.2	-7.5	-17.7	-18.3	-24.6	2.7	4.4	-0.1	-2.3	-6.3
Slovak Republic	2,335	-4.5	-16.1	-25.5	-14.4	-17.5	3.4	-2.3	-0.1	-2.6	-7.7
Slovenia	1,311	-2.8	-17.2	-26.3	-16.6	-17.7	-3.2	-13.2	-0.3	-1.3	-3.1
EU-N12	70,318	1.2	-20.1	-28.9	-19.4	-26.4	-1.6	-7.7	-0.1	-2.3	-6.4

6.2 Impact on agricultural activity levels

In all scenarios most of the adjustments to the GHG mitigation policy measures are made through lower activity levels, with largest decreases in agricultural activity projected to take place in the livestock sector of the EU-27. Within the livestock sector, the herd size of beef meat activities is most affected, because reductions of other activities, for example dairy cows, would entail higher economic losses per unit of emission savings. Table 12 shows how the effect of the homogenous emission standards of 19% and 28% are distributed across activities in the EU-27. In both scenarios, herd size of beef meat activities is most affected, decreasing by 31.1% and 49.7% respectively. However, this sharp decrease in herd sizes is not fully reflected in supply, which decreases by 17.8% and 29.2% respectively. That supply in beef meat activities decreases less than herd size indicates a change in herd structure, decreasing the pure beef producing herd and using more the offspring of the dairy herd for meat production. This change is also reflected in Table 15, on the change in beef herd size and production at Member State level. However, it is also projected that both beef herd size and production decreases are a bit more pronounced in the EU-N12 than in the EU-15. For the EU-N12, highest (relative) decreases in herd size and production are projected to take place in Bulgaria, Czech Republic and Lithuania. In the EU-15 Denmark, Portugal and Austria are most affected. In the pig sector, both herd size and production face decreases at EU-27 level. However, some MS show an increase in pork production, related to the relative increase of its profitability and lower GHG emissions per kg of meat compared to other activities (especially beef and dairy production). The activities of the ruminants “milk ewes and goat” as well as “sheep and goat fattening” are rather strongly affected by the GHG mitigation policies implemented. On the other hand, the EU dairy sector is less affected than the beef sector, with reductions in the dairy cow herd of 6.0 % (HOM19) and 10.3% (HOM28) respectively. The reductions in milk production are smaller than the reductions in herd size (-5.4% and -9.1% respectively), indicating only a rather small increase in productivity per cow. At Member State level, developments show the same pattern as for beef meat activities, albeit also at a lower level (cf. Table 16).

For the arable sector a reduction in UAA is projected for both scenarios (6.8% in HOM19 and 12.6% in HOM28). Hectares under production as well as supply decrease for all arable activities in the EU-27, but fodder activities are hit most by the mitigation policy, with area reductions of 14.5% and 26.2% respectively. This reduction in fodder activities is directly related to the decreases in the livestock sector. Due to the decrease in area under production, set aside and follow land would increase remarkably by 22.6% in HOM19 and 39.8% in HOM28. Looking closer into the projected changes in the cereal sector, area under production is decreasing by 4.7% in HOM19 and 9.5% in HOM28 at EU-27 level, with decrease in production being less (-4.0% and -8.1% respectively). However, the cereal sector in the EU-N12 is more hit by the policy introduced, with production decreases of 5.8% in HOM19 and 11.8% in HOM28, whereas the EU-15 shows reductions in cereal production of 3.2% and 6.6% respectively. At Member State level, Bulgaria, Malta, Latvia, Cyprus and Czech Republic show the highest decreases in cereals production. It has to be pointed out that six of the MS actually increase cereal production in HOM19 and five MS in HOM28, with three MS (Netherlands, Denmark, and UK) having even higher production increases in HOM28 than in HOM19 (cf. Table 17).

Table 12: Change in area, herd size and supply for the EU-27 for activity aggregates according to the HOM19 and HOM28 scenarios

	REF		HOM19		HOM28	
	Hectares or herd size	Supply	Hectares or herd size	Supply	Hectares or herd size	Supply
	1000 ha or hds	1000 t, 1000 ha	% difference to REF			
Utilized agricultural area	181,693	na	-6.8	na	-12.6	na
Cereals	52,856	320,148	-4.7	-4.0	-9.5	-8.1
Oilseeds	11,856	34,291	-4.7	-4.8	-8.6	-8.6
Other arable crops	5,783	164,260	-1.4	na	-2.7	na
Vegetables and Permanent crops	25,060	130,747	0.1	na	0.1	na
Fodder activities	77,391	33,378	-14.5	-16.8	-26.2	-28.3
Set aside and fallow land	8,746	na	22.6	na	39.8	na
Dairy cows	21,722	160,509	-6.0	-5.3	-10.3	-9.1
Beef meat activities	18,213	7,992	-31.1	-17.8	-49.7	-29.1
Pig fattening	252,970	23,494	-5.3	-5.5	-8.2	-8.7
Pig Breeding	15,037	259,528	-5.5	-5.3	-8.6	-8.2
Milk Ewes and Goat	74,090	5,141	-13.4	-8.6	-24.8	-17.9
Sheep and Goat fattening	48,548	742	-13.1	-12.1	-23.7	-21.8
Laying hens	459	7,776	-1.8	-1.6	-3.3	-2.8
Poultry fattening	6,703	13,518	-3.0	-2.8	-5.3	-5.1

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

Table 13 presents how agricultural activities in the EU-27 are affected by the heterogeneous distribution of GHG emission obligations in the scenarios HET19 and HET28. It can be seen that the production effects are of similar nature at EU-27 level as those projected and described for the scenarios with the homogenous emission reduction commitments. However, as emission reduction commitments are generally less in the EU-N12, the distribution of the effects is different from those in the HOM19 and HOM28 scenarios. As can be expected, production effects on the beef meat herd are most pronounced in those EU-15 MS that are confronted with the highest mitigation obligations, such as Denmark, (-65.2% reduction in beef herd size in scenario HET19), Austria (-58.7), Sweden (-57%) and the Netherlands (-56.8%). Again, effects on beef meat production are smaller than those on the herd size, indicating a change in herd structure. For the EU-15 a reduction of the beef herd size of 37.6% is projected in HET19 (56.5% in HET28) and for beef production a reduction of 22.3% (34.3% in HET28). Due to lower GHG mitigation commitments, the EU-N12 can partially compensate for the decrease in the EU-15, actually increasing its beef herd size by 2.4% and production by 2.1% in the HET19 scenario. Due to the stricter reduction limits, herd size and production also decrease in EU-N12 in the HET28 scenario, and while herd size is projected to decrease by 10.2%, production decreases only moderately by 2.5%. Looking at the overall effect at EU-27 level it can be seen that the increases in the EU-N12 MS cannot fully compensate for the decreases in the EU-15 MS, which leads to an overall reduction in

EU-27 beef meat production of 19.7% in the HET19 scenario (compared to 17.8% in HOM19) and of 31.0% in the HET28 scenario (compared to 29.1% in HOM28) (cf. Table 15). Similar to the HOM scenarios, only some EU-15 MS show increases in pig herd size and pork production. On the other hand, all EU-N12 MS but Cyprus and Malta, take advantage of their lower GHG mitigation commitments and increased profitability in the pig sector (relative to ruminant activities).

In the arable sector, effects on area and production are also less pronounced at EU-27 level in the scenarios with the heterogeneous distribution of GHG mitigation commitments compared to those in the HOM scenarios. For example, cereals production in the EU-27 is projected to decrease by 3.3% in HET19 (compared to 4.7% in HOM19), with production decreasing by 5.5% in the EU-15 while increasing by 2.9% in the EU-N12. In the HET28 scenario, the decrease in cereal production at EU-27 level is 6.2% (compared to 8.1% in HOM28), and while production decreases in the EU-15 by 10.1%, it increases in the EU-N12 by 3.4%) (cf. Table 17).

Table 13: Change in area, herd size and supply for the EU-27 for activity aggregates according to the HET19 and HET28 scenarios

	REF		HET19		HET28	
	Hectares or herd size	Supply	Hectares or herd size	Supply	Hectares or herd size	Supply
	[1000 ha or hds]	[1000 t, 1000 ha]	% difference to REF			
Utilized agricultural area	181,693	na	-6.8	na	-12.4	na
Cereals	52,856	320,148	-3.3	-3.1	-6.7	-6.2
Oilseeds	11,856	34,291	-2.3	-2.7	-4.9	-5.6
Other arable crops	5,783	164,260	-1.4	na	-2.9	na
Vegetables and Permanent crops	25,060	130,747	0.1	na	0.1	na
Fodder activities	77,391	33,378	-14.5	-19.4	-25.5	-31.2
Set aside and fallow land	8,746	na	10.5	na	17.6	na
Dairy cows	21,722	160,509	-4.9	-5.0	-8.8	-8.7
Beef meat activities	18,213	7,992*	-35.2	-19.7	-53.8	-31.0
Pig fattening	252,970	23,494	-5.5	-5.7	-8.5	-8.9
Pig Breeding	15,037	259,528	-5.1	-5.5	-7.9	-8.5
Milk Ewes and Goat	74,090	5,141	-12.4	-5.8	-21.8	-11.9
Sheep and Goat fattening	48,548	742	-13.4	-12.7	-23.2	-21.9
Laying hens	459	7,776	-1.6	-1.4	-2.9	-2.5
Poultry fattening	6,703	13,518	-2.5	-2.4	-4.5	-4.3

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

Table 14 presents the effects of the homogenous emission standards with trade of emission permits on agricultural activities in the EU-27. Even though the general nature of the production effects are similar at EU-27 level as those projected and described for the HOM and HET scenarios, several differences can be seen. Again, beef meat activities are most affected, with an overall decrease in herd size of 32.5% in HOM19ET (-52.2% in HOM28ET) and a decline in production of 17.6% (28.9% in HOM28ET). However, despite of a stronger decline in the herd size, beef output is declining less (by 29.0% under HOM28ET) than without emission trading at the EU-27 level (-29.2% under HOM28). This indicates already that beef herds are reduced more in regions with a lower productivity. Moreover, the stronger decline of beef (and sheep & goat) herds in the scenarios with emission permits allows to reduce the EU-27 cuts in activity levels of dairy, pigs and poultry (see Table 12 and Table 14), i.e. activities that typically generate higher income.

Table 14: Change in area, herd size and supply for the EU-27 for activity aggregates according to the HOM19ET and HOM28ET scenarios

	REF		HOM19ET		HOM28ET	
	Hectares or herd size	Supply	Hectares or herd size	Supply	Hectares or herd size	Supply
	[1000 ha or hds]	[1000 t, 1000 ha]	% difference to REF			
Utilized agricultural area	181,693	na	-6.5	na	-12.6	na
Cereals	52,856	320,148	-4.7	-3.8	-8.5	-6.9
Oilseeds	11,856	34,291	-4.5	-4.5	-7.7	-7.7
Other arable crops	5,783	164,260	-1.4	na	-2.6	na
Vegetables and Permanent crops	25,060	130,747	0.1	na	0.1	na
Fodder activities	77,391	33,378	-14.4	-14.2	-27.0	-24.4
Set aside and fallow land	8,746	na	26.8	na	40.8	na
Dairy cows	21,722	160,509	-5.1	-4.4	-8.8	-7.6
Beef meat activities	18,213	7,992	-32.5	-17.6	-52.2	-28.9
Pig fattening	252,970	23,494	-4.2	-4.3	-6.6	-6.8
Pig Breeding	15,037	259,528	-4.5	-4.2	-7.1	-6.6
Milk Ewes and Goat	74,090	5,141	-15.5	-9.4	-27.6	-15.4
Sheep and Goat fattening	48,548	742	-15.2	-14.4	-28.1	-26.9
Laying hens	459	7,776	-1.5	-1.3	-2.5	-2.2
Poultry fattening	6,703	13,518	-2.5	-2.3	-4.3	-4.0

Note: na = not applicable; total supply of beef includes beef from dairy cows and calves

Looking at MS level, the differences to the HOM scenarios become more evident. For example in the EU-N12, Malta and Bulgaria decrease their beef herd size by respectively 34.0 and 21.7 percentage points less in HOM19ET compared to HOM19. In the EU-15, especially Austria, the Netherlands and Denmark show less decrease in beef herd size compared to HOM19 (with 25.3, 18.0 and 13.5 percentage points respectively less decrease in HOM19ET compared to HOM19). By contrast, there are seven MS where the beef herd size is decreasing more in the scenarios with emission trading compared to the HOM scenarios. This is particularly the case in Romania, the UK and Greece; with beef herds decreasing in HOM19ET by a further 27.2, 19.6 and 8.1 percentage points respectively compared to HOM19. The further decrease in the beef herd size of the seven MS can also be observed in the HOM28ET scenario compared to HOM28 (cf. Table 15). The further decrease in beef meat activities contributes most to these countries' additional reductions in GHG emissions compared to the scenarios without emission trading (cf. Table 11), indicating that in these MS it is generally more beneficial for the farmers to reduce beef meat activities and sell emission permits (instead of buying permits in order to keep a higher level of beef meat activities).

With regard to dairy cow herd size and production, decreases in the dairy cow herd at EU-27 level are lower in the scenarios with emission trading than in the HOM scenarios (-5.1% in HOM19ET compared to -6.0% in HOM19; -8.8% in HOM28ET compared to -10.3% in HOM28), and also supply is considerably less affected; with -4.4% in HOM19ET (-5.3 in HOM19) and -7.6% in HOM28ET (-9.1% in HOM28). Nonetheless, for eight MS (including Romania, Estonia and the UK) the dairy herd size is actually slightly more decreasing in the scenarios with the emission permits trading than in the HOM scenarios (cf. Table 16). In the arable sector, effects on area and production are also a bit less pronounced for cereals and oilseeds compared to the HOM scenarios. At EU-27 level, cereals area is decreasing by 4.7% in HOM19ET (8.5% in HOM28ET), whereas production is decreasing less than area (3.8 in HOM19ET and 6.9 in HOM28ET). Decreases in EU-15 cereals area and production are lower than the EU-27 average, with area decreasing by 3.8 % in HOM19ET (7.2% in HOM28ET) and production by 2.8% (5.5% in HOM19ET). By contrast, the decreases in the EU-N12 are higher than the EU-27 average, with cereal area decreasing by 6.3% in HOM19ET (10.9% in HOM28ET) and production by 6.0% (10.4% in HOM28ET) (Table 17).

As a final remark it may be mentioned that the results of the scenarios with emission trading are only marginally affected by the assumed transactions costs. Considering only the 28% reduction version, EU27 milk production is declining by 7.50% entirely *without* transactions costs against the reference scenario rather than 7.51%% *with* transaction costs. Larger differences may only be observed at the country or even regional level, in particular when looking at single activities rather than activity aggregates, for example “fattening of bulls in high intensity”. This activity declines in Estonia (Lithuania) by 57.0% (74.8%) *without* transaction costs but by 56.2% (75.5%) *with* transaction costs considered. Also the price effects do not depend critically on the transaction cost assumption: The largest difference is observed for producer prices of sheep meat, increasing by 34.8% *without* and by 34.6% *with* transaction costs included, in line with a slightly higher production decline *without* (-27.9%) compared to the reduction scenario HOM28ET *with* transaction costs (-27.7%). The opposite effects may be observed for pork and poultry meats but the differences do not exceed 0.1% at the EU27 level. The small size of the additional effects from removing the transactions cost relate to the fact that this last step only achieves a tiny additional unification of marginal GHG abatement costs. These were varying from 113 euros to 1407 euros under HOM28 but only from 613 euros to 624 euros under HOM28ET and finally from 619 to 620 Euros without transactions costs, always per tonne of CO_2.

Table 15: Change in beef herd size and production per EU Member State for all mitigation scenarios

	REF		HOM19		HOM28		HOM19ET		HOM28ET		HET19		HET28	
	Herd size	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.
	1000 hds	1000 t	% difference to REF											
EU-27	18,213	7,992	-31.1	-17.8	-49.7	-29.1	-32.5	-17.6	-52.2	-28.9	-35.2	-19.7	-53.8	-31.0
Austria	410	205	-49.3	-26.8	-62.8	-37.3	-24.0	-15.0	-41.4	-24.2	-58.7	-32.5	-67.0	-43.1
Belgium-Lux	521	285	-30.4	-19.6	-51.1	-31.9	-20.6	-14.1	-36.1	-23.4	-39.8	-25.1	-60.2	-37.5
Denmark	132	125	-57.3	-20.7	-67.9	-33.5	-43.8	-16.4	-59.9	-24.7	-65.2	-30.2	-82.3	-49.6
Finland	149	81	-36.4	-16.5	-49.5	-25.1	-39.3	-17.9	-53.3	-29.4	-46.4	-21.9	-53.5	-29.9
France	4,923	1,688	-24.3	-14.9	-47.1	-27.8	-24.0	-15.8	-44.1	-26.9	-32.5	-19.6	-57.1	-32.6
Germany	1,288	1,048	-33.6	-21.0	-53.6	-35.2	-31.3	-18.9	-47.6	-30.4	-41.3	-25.8	-60.3	-40.6
Greece	194	58	-25.4	-5.9	-62.3	-16.5	-33.5	-9.7	-62.0	-15.2	-3.9	-0.1	-50.3	-7.9
Ireland	2,047	619	-35.1	-18.5	-48.2	-26.4	-41.5	-22.7	-59.0	-41.0	-47.9	-27.1	-57.0	-38.6
Italy	1,150	755	-19.9	-13.9	-36.9	-25.1	-9.2	-7.2	-15.8	-10.9	-24.6	-16.6	-41.3	-28.0
Netherlands	143	380	-41.9	-23.4	-65.7	-36.2	-23.9	-17.4	-43.1	-27.5	-56.8	-30.1	-76.3	-42.6
Portugal	458	122	-48.9	-21.1	-62.2	-27.9	-36.3	-14.7	-64.4	-23.6	-32.1	-13.2	-49.3	-18.9
Spain	2,191	641	-44.8	-17.8	-62.7	-25.7	-43.6	-17.4	-71.2	-27.4	-44.1	-17.3	-64.1	-24.9
Sweden	334	152	-45.2	-27.2	-61.0	-40.3	-32.1	-19.5	-52.8	-31.2	-57.0	-35.9	-68.2	-49.5
UK	3,203	1,007	-23.0	-15.2	-40.7	-25.7	-42.6	-27.7	-66.1	-46.0	-32.8	-21.0	-50.4	-32.2
EU-15	17,144	7,166	-30.7	-17.7	-49.5	-29.1	-32.4	-17.8	-52.6	-29.4	-37.6	-22.3	-56.5	-34.3
Bulgaria	46	30	-74.8	-28.6	-78.9	-33.8	-53.1	-14.1	-71.8	-20.4	-6.5	-3.0	-22.1	-8.7
Cyprus	2	4	-25.1	-13.2	-33.0	-15.4	-10.3	-1.5	-12.8	0.0	-15.3	-10.4	-24.6	-17.7
Czech Republic	157	72	-57.6	-24.5	-75.0	-41.5	-56.7	-23.4	-68.0	-33.9	-2.2	2.9	-27.8	-4.9
Estonia	19	19	-25.3	-14.8	-34.4	-19.1	-32.4	-20.1	-53.3	-33.0	3.3	1.7	-6.1	-4.0
Hungary	45	33	-38.0	-6.7	-51.3	-16.2	-43.8	-13.0	-51.0	-18.1	9.2	5.3	-1.3	4.2
Latvia	12	21	-42.3	-31.6	-51.0	-36.0	-31.1	-22.8	-50.8	-37.0	-11.2	-8.1	-22.8	-16.4
Lithuania	33	40	-53.5	-30.2	-72.7	-36.3	-40.8	-23.2	-66.8	-36.2	-4.2	-3.7	-19.8	-13.3
Malta	3	2	-45.5	-34.2	-64.4	-48.2	-11.5	-8.8	-17.8	-13.5	-11.9	-10.4	-27.7	-22.8
Poland	473	396	-27.0	-22.5	-42.4	-34.1	-20.9	-16.3	-32.3	-25.3	5.2	2.3	-0.7	-3.3
Romania	92	134	-6.5	-2.5	-33.9	-12.8	-33.7	-13.5	-53.2	-22.5	4.7	3.4	7.0	5.3
Slovak Republic	38	26	-29.0	-6.6	-42.1	-15.2	-22.2	-4.6	-32.5	-6.0	13.7	8.9	11.1	10.3
Slovenia	149	48	-52.1	-15.9	-62.6	-31.8	-50.8	-14.0	-52.4	-15.8	-2.3	4.4	-33.4	-4.8
EU-N12	1,069	826	-36.9	-18.5	-52.1	-29.6	-34.7	-16.2	-46.2	-24.8	2.4	2.1	-10.2	-2.5

Table 16: Change in dairy herd size and milk production per EU Member State for all mitigation scenarios

	REF		HOM19		HOM28		HOM19ET		HOM28ET		HET19		HET28	
	Herd size	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.
	[1000 hds]	[1000 t]	% difference to REF											
EU-27	21,722	160,509	-6.0	-5.3	-10.3	-9.1	-5.1	-4.4	-8.8	-7.6	-4.9	-5.0	-8.8	-8.7
Austria	542	3,622	-10.5	-10.1	-14.9	-14.3	-4.6	-4.5	-7.9	-7.6	-13.2	-12.7	-19.1	-18.4
Belgium-Lux	635	5,000	-5.9	-5.5	-9.7	-9.2	-3.6	-3.3	-6.1	-5.7	-8.0	-7.6	-12.7	-12.1
Denmark	495	4,813	-7.1	-6.8	-13.9	-13.2	-5.0	-4.7	-8.1	-7.6	-13.8	-13.2	-25.6	-24.5
Finland	241	2,482	-5.2	-4.8	-7.2	-6.5	-5.8	-5.4	-9.8	-9.1	-7.1	-6.6	-9.7	-8.8
France	3,287	24,613	-1.2	-0.9	-3.2	-2.9	-1.9	-1.6	-3.4	-2.9	-2.4	-2.1	-4.7	-4.3
Germany	3,853	30,443	-4.9	-4.6	-9.0	-8.4	-4.7	-4.4	-8.0	-7.4	-6.6	-6.3	-11.4	-10.7
Greece	128	769	5.0	6.0	6.1	8.1	2.7	4.2	4.2	7.0	7.8	8.1	9.7	11.2
Ireland	1,390	7,788	-5.5	-5.2	-8.2	-7.7	-7.3	-7.0	-14.4	-13.8	-9.2	-8.7	-13.6	-12.9
Italy	1,768	13,295	-4.6	-5.1	-9.3	-9.6	-0.7	-0.5	-1.4	-1.0	-5.9	-6.3	-11.6	-11.6
Netherlands	1,540	14,000	-10.8	-10.4	-16.8	-16.2	-5.9	-5.6	-10.1	-9.7	-14.4	-14.0	-21.7	-21.0
Portugal	209	1,911	-10.5	-9.1	-14.5	-12.8	-3.4	-3.2	-5.8	-5.5	-5.3	-4.2	-8.2	-6.7
Spain	834	6,977	-1.5	-0.9	-2.6	-1.7	-1.1	-0.8	-1.7	-1.1	-0.8	-0.2	-2.1	-1.1
Sweden	369	3,430	-6.9	-6.3	-10.8	-10.0	-4.5	-4.1	-7.4	-6.8	-10.0	-9.3	-15.3	-14.2
UK	1,697	14,610	-1.6	-1.1	-2.0	-1.2	-4.8	-4.3	-8.9	-8.0	-2.7	-2.0	-3.9	-2.9
EU-15	16,988	133,751	-4.6	-4.3	-7.9	-7.5	-3.8	-3.5	-6.7	-6.1	-6.4	-6.1	-10.6	-10.1
Bulgaria	239	1,017	-20.3	-19.4	-30.2	-28.6	-11.6	-10.9	-20.0	-18.8	-0.7	-0.6	-3.6	-3.3
Cyprus	24	177	-6.5	-5.7	-9.4	-8.2	-1.9	-1.5	-3.0	-2.2	-4.6	-4.3	-7.5	-6.9
Czech Republic	301	2,662	-7.6	-6.5	-14.1	-12.5	-6.8	-5.9	-11.1	-9.6	0.9	1.1	-1.2	-0.5
Estonia	97	728	-4.5	-3.9	-5.4	-4.3	-8.0	-7.3	-13.4	-12.3	1.6	1.7	0.1	0.4
Hungary	191	1,493	-3.8	-3.3	-12.2	-11.0	-7.5	-6.8	-12.6	-11.4	2.3	2.4	2.0	2.2
Latvia	148	775	-14.9	-13.4	-17.8	-15.6	-10.8	-9.7	-18.5	-16.5	-3.2	-2.8	-6.7	-5.9
Lithuania	319	1,625	-16.9	-15.4	-23.3	-21.0	-13.1	-11.9	-22.0	-20.0	-1.1	-0.9	-5.7	-5.0
Malta	9	55	-17.2	-16.1	-25.8	-23.9	-5.6	-5.2	-9.4	-8.6	-5.4	-5.2	-11.4	-10.8
Poland	2,321	12,980	-15.6	-14.7	-24.1	-22.7	-10.8	-10.1	-18.1	-16.8	-0.7	-0.5	-4.6	-4.1
Romania	867	3,854	0.2	0.7	-5.7	-4.6	-7.5	-6.9	-12.9	-11.7	2.7	2.8	4.8	4.9
Slovak Republic	116	788	-7.0	-6.1	-18.0	-16.9	-5.5	-5.0	-9.3	-8.5	3.3	3.3	3.0	3.3
Slovenia	104	602	-5.2	-4.5	-16.0	-14.5	-4.3	-3.8	-7.6	-6.6	0.9	0.9	-1.6	-1.2
EU-N12	4,734	26,758	-11.3	-10.4	-18.9	-17.4	-9.6	-8.7	-16.2	-14.6	0.2	0.4	-2.2	-1.8

Table 17: Change in cereal area and production per EU Member State for all mitigation scenarios

	REF		HOM19		HOM28		HOM19ET		HOM28ET		HET19		HET28	
	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.
	[ha]	[1000 t]	% difference to REF											
EU-27	52,856	320,148	-4.7	-4.0	-9.5	-8.1	-4.7	-3.8	-8.5	-6.9	-3.3	-3.1	-6.7	-6.2
Austria	768	5,472	-3.3	-5.6	-5.5	-8.0	-1.1	-1.3	-2.2	-2.5	-5.0	-8.6	-7.5	-11.0
Belgium-Lux	319	3,116	-4.5	-5.0	-9.4	-9.9	-3.2	-2.9	-7.5	-6.6	-8.1	-9.1	-14.8	-16.0
Denmark	1,336	9,754	3.2	3.6	4.6	5.4	2.5	3.2	4.6	6.0	3.6	3.0	0.5	-0.4
Finland	1,088	4,369	-8.8	-7.1	-15.4	-12.6	-11.3	-9.8	-20.5	-18.3	-13.0	-11.4	-20.1	-17.7
France	9,082	73,687	-4.7	-3.0	-9.5	-6.5	-4.6	-3.0	-8.6	-5.7	-7.1	-5.4	-12.2	-9.5
Germany	6,525	52,446	-6.2	-5.4	-12.6	-10.8	-6.0	-5.1	-11.0	-9.2	-9.2	-8.6	-17.3	-15.7
Greece	1,007	4,694	0.3	2.0	-2.2	-0.6	-1.2	-0.5	-1.9	-0.7	2.2	4.8	0.8	3.5
Ireland	302	2,625	3.7	4.7	-1.7	0.4	1.1	1.9	-11.4	-10.2	-4.7	-4.2	-13.3	-12.1
Italy	3,310	19,685	-5.8	-7.5	-11.8	-14.1	-3.6	-3.3	-5.4	-4.8	-8.0	-10.2	-15.3	-18.3
Netherlands	192	2,015	4.6	6.0	3.6	6.4	5.9	7.3	5.6	8.3	2.7	4.0	1.3	3.8
Portugal	299	1,143	-9.1	-9.8	-5.1	-7.9	-8.6	-8.1	-10.0	-10.4	-6.8	-5.7	-3.3	-4.6
Spain	5,880	20,625	-2.9	-3.5	-5.5	-5.6	-2.2	-2.8	-5.2	-5.7	-3.3	-4.0	-6.5	-6.9
Sweden	869	4,984	-8.2	-6.3	-12.9	-9.8	-6.6	-4.9	-10.6	-7.7	-12.2	-10.3	-18.0	-15.2
UK	2,665	21,382	0.5	2.0	-0.1	2.9	-0.8	0.6	-2.5	0.1	-0.5	0.8	-2.1	0.7
EU-15	33,642	225,996	-4.0	-3.2	-8.1	-6.6	-3.8	-2.8	-7.2	-5.5	-5.9	-5.5	-11.0	-10.1
Bulgaria	1,573	7,932	-18.7	-19.6	-26.5	-27.3	-9.1	-8.9	-15.4	-14.8	-0.6	1.0	-2.9	-0.8
Cyprus	56	109	-10.2	-12.2	-13.0	-14.1	-4.8	-5.2	-7.6	-8.2	-6.4	-7.5	-10.5	-12.3
Czech Republic	1,647	9,738	-9.9	-11.1	-18.1	-19.9	-7.1	-7.7	-12.0	-13.0	0.2	1.7	-2.2	-0.6
Estonia	258	914	-2.4	-1.2	-6.2	-3.5	-6.2	-5.5	-20.7	-19.3	3.1	4.6	4.5	6.8
Hungary	2,420	16,043	-2.4	-0.4	-7.8	-5.5	-5.0	-3.8	-8.3	-6.5	2.0	4.1	2.0	5.5
Latvia	575	2,486	-14.0	-13.3	-16.2	-14.0	-7.8	-7.2	-16.5	-14.8	-1.2	-0.5	-3.0	-1.4
Lithuania	876	3,982	-0.4	-3.7	-1.7	-4.8	0.8	-1.4	-1.1	-4.3	1.8	2.7	3.6	4.3
Malta	3	18	-15.0	-14.3	-22.8	-21.4	-5.9	-4.3	-9.1	-6.8	-6.3	-5.5	-11.8	-10.6
Poland	6,737	29,792	-8.5	-9.3	-16.0	-17.5	-7.3	-8.1	-12.5	-13.7	0.6	2.5	-0.8	1.7
Romania	4,264	18,467	1.4	3.5	-2.5	0.7	-5.9	-4.5	-9.7	-7.5	3.0	4.6	5.6	8.5
Slovak Republic	716	3,961	-3.4	-2.4	-9.1	-8.4	-2.5	-1.2	-4.1	-2.0	1.1	2.9	0.9	3.9
Slovenia	88	708	-3.5	-3.3	-10.1	-11.5	-2.4	-1.6	-4.4	-3.2	-0.5	0.7	-1.8	-0.4
EU-N12	19,214	94,152	-6.0	-5.8	-11.9	-11.8	-6.3	-6.0	-10.9	-10.4	1.2	2.9	0.9	3.4

Table 18: Change in pig numbers and pork production per EU Member State for all mitigation scenarios

	REF		HOM19		HOM28		HOM19ET		HOM28ET		HET19		HET28	
	Herd size	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.
	[1000 hds]	[1000 t]	% difference to REF											
EU-27	252,970	24,287	-5.3	-5.5	-8.2	-8.7	-4.2	-4.3	-6.6	-6.8	-5.5	-5.7	-8.5	-8.9
Austria	5,033	561	-7.9	-7.9	-9.5	-9.4	-3.3	-3.3	-5.1	-5.0	-11.0	-11.0	-13.3	-13.2
Belgium-Lux	10,945	1,146	-7.2	-7.2	-11.3	-11.2	-3.8	-3.8	-6.3	-6.2	-10.5	-10.4	-15.5	-15.4
Denmark	24,729	1,946	-0.7	-0.9	-2.4	-2.7	-0.3	-0.4	0.1	-0.1	-7.5	-7.9	-13.5	-14.1
Finland	1,903	177	2.1	1.8	4.9	4.4	-3.4	-3.8	-5.4	-6.2	0.6	0.2	3.9	3.3
France	26,539	2,530	-3.6	-3.4	-8.8	-8.5	-5.1	-5.0	-8.4	-8.2	-6.3	-6.1	-12.3	-11.9
Germany	49,659	5,424	-7.3	-7.0	-11.5	-11.1	-6.0	-5.9	-9.9	-9.7	-9.6	-9.3	-14.4	-13.9
Greece	1,524	104	5.8	5.8	6.8	6.7	1.3	1.2	2.5	2.3	10.1	10.3	13.9	14.0
Ireland	3,524	265	2.9	3.0	7.5	7.7	-0.4	-0.4	-0.9	-0.8	2.3	2.4	6.9	7.1
Italy	13,358	1,794	-8.5	-8.5	-15.7	-15.7	-2.3	-2.2	-3.4	-3.3	-10.7	-10.7	-18.4	-18.4
Netherlands	20,006	1,582	-5.1	-5.3	-6.7	-7.1	-3.5	-3.7	-5.0	-5.2	-8.4	-8.8	-10.3	-10.8
Portugal	5,517	369	-5.8	-6.0	-5.9	-6.3	-3.5	-3.6	-5.2	-5.4	1.2	1.2	2.8	2.7
Spain	44,276	3,961	-8.1	-8.3	-10.1	-10.4	-5.1	-5.2	-7.5	-7.7	-6.6	-6.7	-8.5	-8.7
Sweden	2,407	241	-5.3	-5.2	-8.0	-7.8	-5.1	-5.0	-8.1	-8.1	-10.7	-10.6	-14.6	-14.5
UK	8,452	682	5.1	5.1	9.2	9.2	-1.8	-1.9	-3.1	-3.3	4.1	4.0	8.1	8.0
EU-15	217,873	20,782	-5.3	-5.6	-8.1	-8.6	-4.0	-4.2	-6.3	-6.5	-7.2	-7.5	-10.7	-11.3
Bulgaria	700	60	-0.6	-1.6	2.0	0.8	1.8	1.5	3.3	2.8	7.4	7.2	11.4	11.0
Cyprus	796	69	-18.2	-18.9	-26.0	-27.1	-6.1	-6.4	-9.6	-10.1	-11.1	-11.6	-18.8	-19.7
Czech Republic	2,848	297	-8.8	-8.9	-16.6	-16.7	-8.2	-8.3	-13.5	-13.6	4.0	4.0	2.7	2.7
Estonia	693	62	4.3	4.4	10.2	10.4	0.2	0.2	0.6	0.6	6.9	7.0	10.1	10.2
Hungary	3,220	376	-0.5	-0.4	-8.8	-8.8	-7.0	-7.0	-11.5	-11.5	7.3	7.3	9.6	9.7
Latvia	699	68	-8.6	-8.6	-5.9	-6.0	-5.9	-5.9	-9.5	-9.6	0.8	0.8	0.5	0.5
Lithuania	1,273	111	-1.8	-1.8	2.0	2.0	-1.1	-1.1	-1.4	-1.4	5.3	5.3	7.1	7.1
Malta	83	8	-19.0	-19.6	-25.0	-25.9	-2.9	-3.0	-4.2	-4.6	-5.2	-5.6	-11.2	-11.8
Poland	20,095	1,962	-8.2	-8.2	-12.1	-12.0	-6.1	-6.1	-9.5	-9.5	4.6	4.7	4.2	4.3
Romania	3,777	384	5.7	5.8	5.9	5.9	-1.4	-1.4	-2.3	-2.3	8.8	8.8	14.5	14.5
Slovak Republic	618	65	0.3	0.4	-9.2	-9.2	-1.3	-1.2	-1.9	-1.9	6.8	6.8	10.5	10.6
Slovenia	295	43	-0.2	-0.5	-7.0	-7.8	-0.6	-0.9	-0.2	-0.6	5.4	5.2	5.3	5.0
EU-N12	35,097	3,506	-5.5	-5.3	-9.1	-9.1	-5.2	-5.3	-8.3	-8.4	5.0	5.1	5.6	5.7

6.3 Impact on EU producer and consumer prices

Due to the large production decreases provoked by the mitigation policies implemented, which are not compensated by equivalent imports, all producer prices in the EU are projected to increase. The relative changes in producer prices for several products are presented in Table 19 according to each scenario. The increases in producer prices are in line with the observed decreases in production in the respective scenarios, reflecting that price increases are highest for beef and milk. As the production decreases are generally lower in the scenarios with emission trading, the producer prices of pig meat, poultry meat and cow milk are considerably less affected than in the respective scenarios without tradable emission permits. The same holds for producer prices of crops, where prices for cereals and oilseeds are less affected than in the scenarios without tradable emission permits.

Table 19: Change in producer price for several products by scenario

	REF	HOM19	HOM28	HOM19ET	HOM28ET	HET19	HET28
	EUR/t	% difference to REF					
Cereals	251	7.2	13.1	6.8	11.8	6.1	11.3
Oilseeds	301	9.5	18.2	8.9	15.8	5.2	10.9
Other arable field crops	124	4.2	7.4	3.6	5.9	4.3	8.1
Vegetables and Permanent crops	869	1.6	2.6	1.4	2.3	1.6	2.7
Beef	5984	35.5	59.9	35.1	60.2	39.8	64.4
Pork meat	2394	21.3	38.3	17.0	29.5	22.9	40.8
Sheep and goat meat	8564	17.3	27.8	20.7	34.3	17.7	26.5
Poultry meat	2131	9.4	16.8	7.9	13.8	9.6	17.0
Cow and buffalo milk	403	37.9	67.9	31.8	55.6	36.7	66.0
Sheep and goat milk	837	21.7	45.0	22.2	38.2	18.9	37.5
Eggs	1595	9.9	17.5	8.6	14.7	10.4	18.0

Regarding consumer prices for crops, the impact of the mitigation policies is between 0.1% and 1.3% (cf. Table 20). The increases of the consumer prices for meat and dairy products are much larger and vary between 5.6% (pork in HOM19ET) and 30.7% (beef in HET28), with the lowest impact being recorded for the scenarios with emission trading. The differential in price increase by meat product leads to a shift in meat consumption. Beef and pork meat consumption per capita is decreasing up to 5.7% and 2.4% respectively, while poultry meat consumption increases. Total meat consumption per capita decreases by maximum 1.6% (HOM28).

Table 20: Change in consumer price for several products by scenario

	REF	HOM19	HOM28	HOM19ET	HOM28ET	HET19	HET28
	EUR/t	% difference to REF					
Cereals	3513	0.5	0.9	0.4	0.8	0.4	0.8
Oilseeds	3962	0.6	1.3	0.6	1.1	0.4	0.9
Other arable field crops	1296	0.3	0.6	0.2	0.5	0.4	0.7
Vegetables and Permanent crops	2368	0.2	0.3	0.1	0.2	0.2	0.4
Beef	11881	16.8	27.9	16.4	27.2	19.3	30.7
Pork meat	7483	7.1	12.7	5.6	9.8	7.6	13.5
Sheep and goat meat	13944	7.5	11.5	8.3	12.8	7.7	11.1
Poultry meat	4817	5.6	10.0	4.8	8.3	6.0	10.6
Eggs	4399	3.6	6.3	3.1	5.3	3.7	6.4
Butter	5915	15.3	25.6	12.9	21.5	15.9	26.9
Cheese	8253	11.7	21.1	9.4	16.6	11.4	20.7

6.4 Impact on EU imports, exports and net trade position

Table 21 presents the change in EU imports, exports and net trade position for aggregate activities according to the HOM19 and HOM28 scenarios. Although emission leakage is only dealt with in the final chapter of this report, changes in trade can give already a hint of the potential impacts. Taking into account the large production drop in the EU in both scenarios, the trade balance is expected to worsen for almost all agricultural products. The mentionable exception are oil cakes because of the lower feed demand from the EU livestock sector. In line with the production developments, changes in EU imports and exports are more pronounced in the livestock than in the crop sector. In a context of decreasing feed use, EU imports of cereals are still increasing by about 31% in HOM19 and by 62% in HOM28, but the main loss is at the export side where the EU decreases its cereals exports by 6.3 million tonnes in HOM28. The dairy sector resists relatively well to import/export changes compared to the meat sector. Still, the dairy exports are declining by 31% in HOM28. The imports of beef increase by 164% in HOM19 and 319% in HOM28, the latter representing an increase of 1.76 million tonnes. Beef exports are decreasing as well, but quantities involved are relatively smaller. In the pork sector, the drop in production is mainly translated into a reduction of the exports by 47% in HOM19 and 70% in HOM28, due to less competitive EU prices.

The changes in EU imports, exports and net trade position for aggregate activities according to the HET19 and HET28 scenarios are presented in Table 22. It can be seen that the changes in crop imports and exports of the heterogeneous scenarios follow a similar pattern as in the homogeneous scenarios, both in level and direction, but the changes are generally less pronounced in the HET scenarios. For the dairy sector, changes are also similar to those in the HOM scenarios, but the EU-27 net trade balance deteriorates a bit less. Beef imports increase by 196% (+1.08 million tonnes) in HET19 and even by 360% (about +1.98 million tonnes) in HET28. Beef exports are decreasing as well, but quantities involved are again relatively smaller. In the pork sector, the production decrease and increase of internal EU agricultural prices result again mainly in a reduction of exports by 50% in HET19 and 73% in HET28.

Table 23 shows the results for the HOM_ET scenarios (i.e. with emission permit trading). The direction of the changes is the same as in the HOM scenarios without permit trading, but in general the impact on the EU net trade position is slightly less in the HOM_ET scenarios. The exception is sheep and goat meat, where imports increase and exports decrease more than in the HOM scenarios.

Table 21: Change in EU imports, exports and net trade position for aggregate activities according to the HOM19 and HOM28 scenarios

	REF			HOM19			HOM28		
	Imports	Exports	Net trade position	Imports	Exports	Net trade position	Imports	Exports	Net trade position
	1000 t			% diff to REF		1000 t	% diff to REF		1000 t
Cereals	10,391	47,140	36,749	31.4	-13.5	27,141	61.5	-23.9	19,108
Oilseeds	24,652	10,376	-14,276	5.2	-5.9	-16,160	10.3	-10.7	-17,928
Other arable field crops	2,048	3,749	1,701	-5.5	-2.3	1,726	-4.0	-6.7	1,533
Vegetables and Permanent crops	25,982	7,394	-18,587	1.6	-1.2	-19,089	2.7	-1.9	-19,443
Oils	10,894	3,766	-7,128	0.6	-3.8	-7,333	1.2	-7.1	-7,531
Oil cakes	23,306	3,375	-19,931	-13.1	7.2	-16,636	-18.9	11.4	-15,147
Beef	552	137	-414	164.4	-88.4	-1,442	318.6	-96.6	-2,304
Pork	6	2,278	2,272	*184.3	-46.8	1,194	*444.0	-70.1	650
Sheep and goat meat	277	20	-257	33.8	-62.5	-363	70.5	-74.9	-467
Poultry meat	252	1,260	1,008	78.4	-25.2	494	172.1	-40.4	66
Dairy products	385	2,746	2,361	40.3	-19.1	1,681	88.7	-31.1	1,166

Note: The reader should be aware that the high percentage difference for pork meat imports in the scenario represents only very small absolute quantities

Table 22: Change in EU imports, exports and net trade position for aggregate activities according to the HET19 and HET28 scenarios

	REF			HET19			HET28		
	Imports	**Exports**	**Net trade position**	**Imports**	**Exports**	**Net trade position**	**Imports**	**Exports**	**Net trade position**
	1000 t			**% diff to REF**		**1000 t**	**% diff to REF**		**1000 t**
Cereals	10,391	47,140	36,749	26.1	-11.5	28,613	50.7	-20.9	21,632
Oilseeds	24,652	10,376	-14,276	2.9	-1.8	-15,170	7.5	-4.2	-16,563
Other arable field crops	2,048	3,749	1,701	-3.9	-4.1	1,626	-1.7	-9.2	1,393
Vegetables and Permanent crops	25,982	7,394	-18,587	1.7	-1.1	-19,102	2.8	-1.9	-19,456
Oils	10,894	3,766	-7,128	0.6	-3.3	-7,322	1.3	-6.3	-7,503
Oil cakes	23,306	3,375	-19,931	-10.4	6.1	-17,294	-15.8	9.6	-15,926
Beef	552	137	-414	195.9	-90.6	-1,619	359.7	-97.1	-2,531
Pork meat	6	2,278	2,272	*181.7	-49.6	1,133	*424.9	-72.7	592
Sheep and goat meat	277	20	-257	35.1	-58.6	-366	69.1	-69.1	-462
Poultry meat	252	1,260	1,008	82.1	-28.0	449	179.2	-43.7	6
Dairy products	385	2,746	2,361	34.6	-19.3	1,698	79.7	-31.5	1,188

Note: The reader should be aware that the high percentage difference for pork meat imports in the scenario represents only very small absolute quantities

Table 23: Change in EU imports, exports and net trade position for aggregate activities according to the HOM19ET and HOM28ET scenarios

	REF			HOM19ET			HOM28ET		
	Imports	Exports	Net trade position	Imports	Exports	Net trade position	Imports	Exports	Net trade position
	1000 t			% diff to REF		1000 t	% diff to REF		1000 t
Cereals	10,391	47,140	36,749	30.9	-13.1	27,364	55.5	-21.9	20,666
Oilseeds	24,652	10,376	-14,276	5.3	-5.2	-16,121	9.4	-9.0	-17,533
Other arable field crops	2,048	3,749	1,701	-5.1	-1.8	1,738	-3.0	-5.5	1,559
Vegetables and Permanent crops	25,982	7,394	-18,587	1.4	-1.1	-19,040	2.4	-1.7	-19,328
Oils	10,894	3,766	-7,128	0.5	-3.9	-7,328	1.1	-6.7	-7,498
Oil cakes	23,306	3,375	-19,931	-11.7	7.0	-16,966	-15.3	9.9	-16,025
Beef	552	137	-414	159.5	-87.8	-1,415	309.4	-96.4	-2,253
Pork meat	6	2,278	2,272	*148.7	-38.5	1,387	*292.6	-58.4	924
Sheep and goat meat	277	20	-257	41.7	-66.0	-385	86.2	-78.0	-511
Poultry meat	252	1,260	1,008	63.9	-21.6	574	130.2	-34.4	247
Dairy products	385	2,746	2,361	30.0	-16.4	1,796	65.7	-26.4	1,384

Note: The reader should be aware that the high percentage difference for pork meat imports in the scenario represents only very small absolute quantities

6.5 Impact on agricultural income

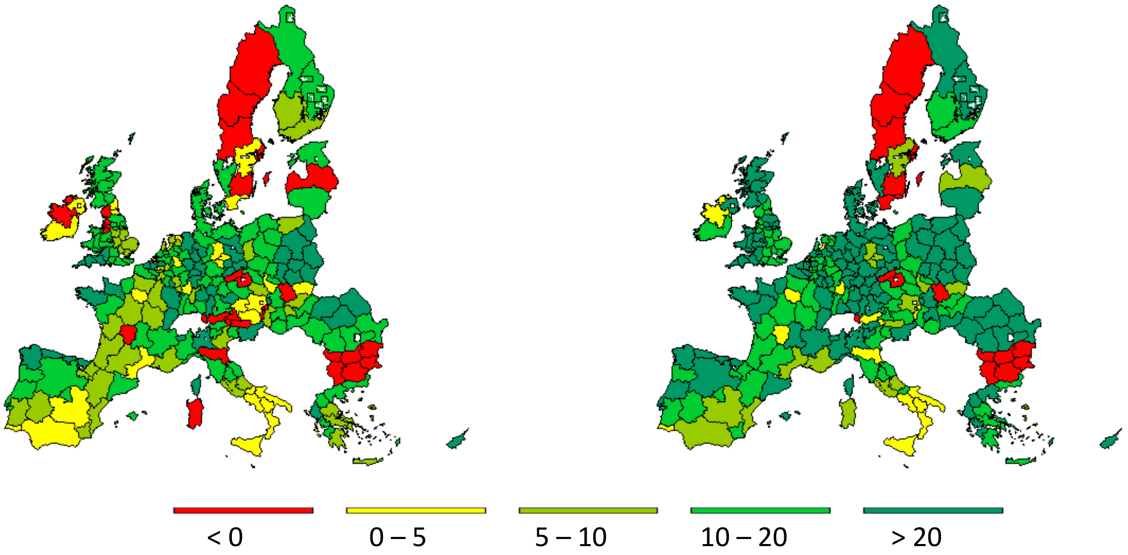
Maps 1 to 3 show the impact of the mitigation policies on total agricultural income by NUTS2 region. Total agricultural income takes into account the changes in the product margins (gross added value - cost) and in the production quantity of all agricultural activities in the particular region. The effect on total agricultural income at aggregated EU-27 level is positive in all mitigation policy scenarios, implying that the income loss due to reduction in area and animal heads would be compensated by the increased yields and producer prices. However, between 5% (HOM28ET and HET28) and 11% (HOM19) of the NUTS2 regions show negative income effects in the simulated mitigation policies with emission reduction targets.

In the HOM19 and HOM28 scenarios, total agricultural income in the EU-27 increases by 16.2% and 27.4% respectively. The impact is positive in 89% of the regions in HOM19 and almost 93% in HOM28 (see map 1). A negative effect at aggregated MS level is projected for Latvia and also for Bulgaria in HOM19, whereas in HOM28 the effect on total agricultural income would be positive for all countries at aggregated MS level. Even though there is a positive effect on agricultural income depicted at aggregated level in Sweden, several Swedish regions would lose. Further negatively affected regions are scattered all over Europe in the HOM19 scenario, with the situation improving in the HOM28 scenario. The change from a negative impact in HOM19 to a positive income impact in HOM28 is due to the higher producer price increase for agricultural products in HOM28, which offsets the decrease in agricultural production.

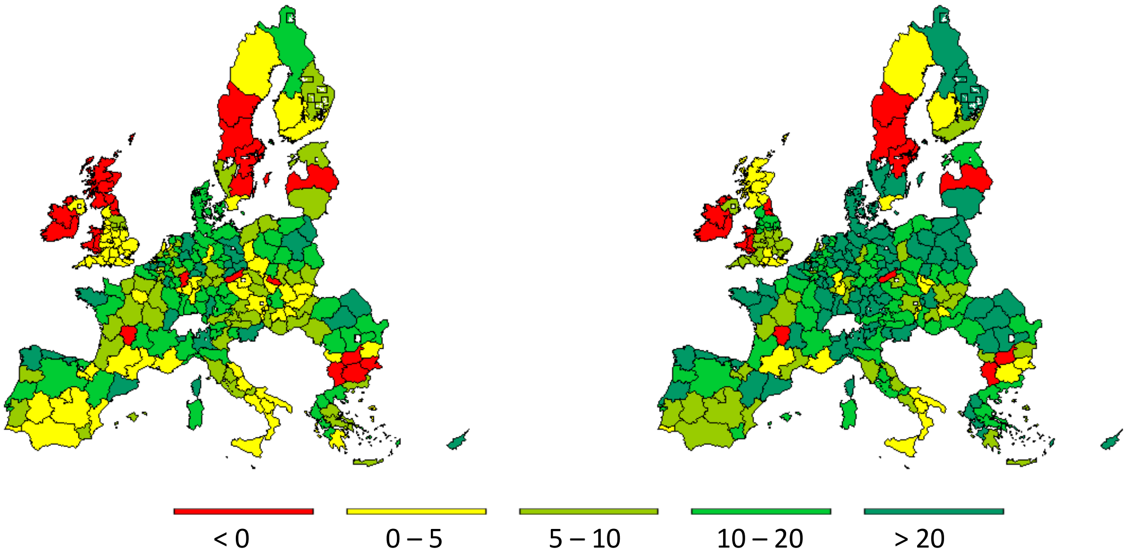
When emission permit trading is allowed, the changes in total agricultural income follow the pattern of the changes observed in production and producer price (see map 2), taking into account the different shares of the production activities in each region. At EU-27 level, total agricultural income increases by 14.3% and 23.1% in the HOM19ET and the HOM28ET respectively. Total agricultural income of about 92% of the regions is positively affected in HOM19ET and in about 95% of the regions in HOM28ET.

In the HET19 and HET28 scenario, total agricultural income shows the biggest increase, by 18.8% and 27.3% respectively, as the production effects are also bigger in the HET scenarios than in the HOM scenarios. Despite the fact that almost all the regions in EU-N12 show a positive impact in the HET scenarios, the percentage income increase in EU-15 is higher than in the EU-N12 (17.2 vs. 13.6 and 27.8 vs. 23.7). However the aggregated result hides large differences between the regions of EU-15.

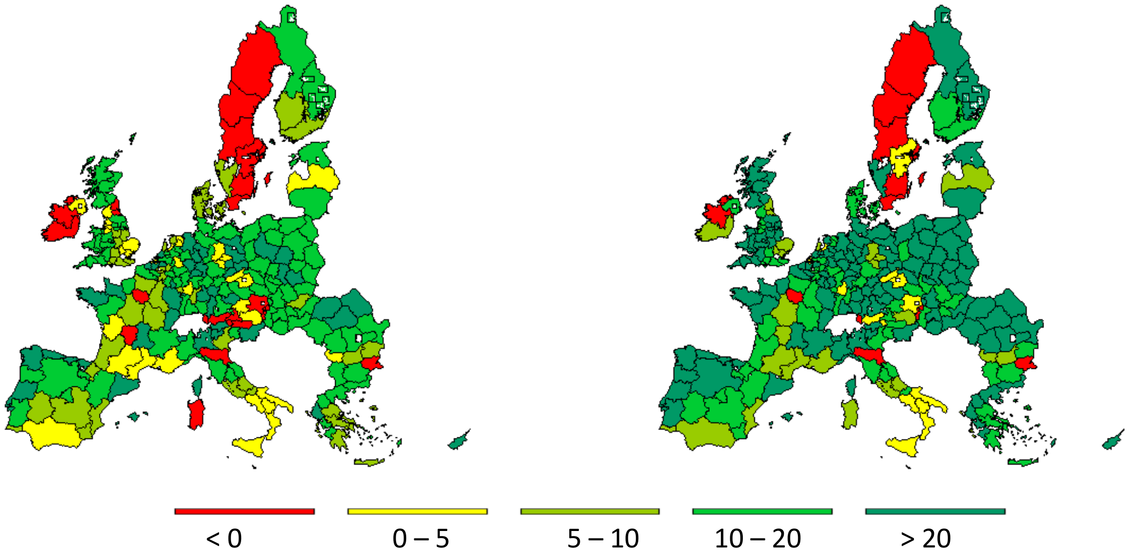
Map 1: **Impact on total agricultural income according to the HOM19 and HOM28 scenarios (% change relative to REF)**



Map 2: **Impact on total agricultural income according to the HOM19ET and HOM28ET scenarios (% change relative to REF)**



Map 3: Impact on total agricultural income according to the HET19 and HET28 scenarios (% change relative to REF)



6.6 Results of the mitigation technology subsidy scenarios

In this subset of scenarios we model the introduction of a subsidy for the implementation and use of (one or more of) the GHG mitigation technologies covered in this study. Contrary to the previous scenarios, no GHG emission reduction targets are defined for the mitigation technology subsidy scenarios. The support schemes assume that the farmers are given a relative subsidy of respectively 30%, 60% and 90% applied to the unit cost (or benefit) of the modelled mitigation technologies. The reader is reminded of the discussion of unobserved costs or benefits in Section 3.2. For those options with zero observed shares (for example all fertiliser related options) but positive accounting cost it has been assumed in an isolated experiment that a subsidy rate of 150% would be needed to achieve a 100% implementation. For the group of late followers even the 90% subsidy will be insufficient for participation but about half of the farmers may be expected to implement the options.

The achieved emission reductions due to the subsidies granted for applying the GHG mitigation technologies are presented in Table 24 according to Member States.[16] As can be expected, the mitigation effect increases with the amount of subsidies paid, since the subsidies lead to a higher uptake of the modeled mitigation technologies.

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[16] A direct comparison of the changes in agricultural GHG emissions in all scenarios is presented in Table 11 (section 6.1).

Table 24: Changes in agricultural GHG emissions per EU Member State in 2030 according to the mitigation technology subsidy scenarios

	SUB30	SUB60	SUB90
	%-change to REF		
EU-27	-0.6	-2.0	-4.5
Austria	0.0	-1.1	-3.2
Belgium-Lux	-2.6	-4.2	-6.1
Denmark	-2.9	-3.8	-5.5
Finland	0.0	-1.0	-2.9
France	-0.5	-1.9	-4.6
Germany	-0.5	-1.9	-4.6
Greece	-0.2	-1.5	-3.8
Ireland	-0.4	-1.2	-2.8
Italy	-0.7	-2.2	-3.7
Netherlands	-1.5	-2.4	-4.4
Portugal	-0.3	-1.1	-2.3
Spain	-0.9	-2.8	-4.8
Sweden	-0.2	-1.2	-3.3
UK	-0.1	-1.1	-3.0
EU-15	-0.7	-1.9	-4.1
Bulgaria	0.0	-3.3	-9.9
Cyprus	-1.6	-3.9	-5.3
Czech Republic	-0.1	-2.6	-7.2
Estonia	-0.1	-1.6	-4.4
Hungary	-0.1	-3.4	-9.5
Latvia	0.0	-1.1	-3.2
Lithuania	0.0	-2.0	-5.8
Malta	-1.3	-3.6	-5.5
Poland	0.0	-1.9	-5.4
Romania	-0.1	-2.3	-6.3
Slovak Republic	-0.1	-2.6	-7.7
Slovenia	-0.3	-1.3	-3.1
EU-N12	-0.1	-2.3	-6.4

In the GAINS database, information on the mitigation technologies for animal production is detailed and differentiated by EU Member State. However, the available information did not permit such differentiation for the fertiliser related mitigation technologies (i.e. timing of fertilisation etc., see below). This implies that for the crop sector the unit cost for the mitigation technologies as well as their implementation levels and derived parameters are considered the same in all MS. Therefore, only EU results are presented in Table 25.

In the SUBS30 scenario, the subsidy scheme has clearly no effect on the implementation of the mitigation technologies for crops, because the subsidy rate is below the assumed threshold for technologies not yet implemented according to the database. In the SUBS60 scenario, 40% of the crops (including grassland) are produced by using one or a combination of mitigation technologies while in SUBS90 a full implementation of the technologies can be observed. The timing of fertilisation represents 10% of the implementation in SUBS60, but the combination with nitrification inhibitors is clearly favoured when the subsidy goes up to 90%. Therefore, we see a reduction from 10% to zero for 'timing of fertilisation', while the 'combination of timing of fertilisation and nitrification inhibitors' shows a further increase from 10% to 32%.

Table 25: Share of crops in EU-27 produced by using mitigation technologies according to the SUBS30, SUBS60 and SUBS90 scenarios (%)

Mitigation technology	REF	SUBS30	SUBS60	SUBS90
No mitigation technology	100	100	60	0
Timing of fertilisation	0	0	10	0
Nitrification inhibitors	0	0	10	31
Precision farming	0	0	10	37
Combination of timing and nitrification inhibitors	0	0	10	32

Focusing on pig fattening in the EU-27, we can see in Table 26 that some MS, like Denmark and Austria, will already implement anaerobic digestion plants in the reference scenario, but most MS are not expected to adopt the technology by 2030. The level of implementation in the subsidy scenarios varies considerably between MS.

Table 26 shows that three groups of countries can be distinguished. The first group implements the anaerobic digestion technology in the SUBS30 scenario already at the maximum level. This is mainly because the negative cost of this technology is relatively high (and the subsidy makes the technology even more attractive) or the implementation in the reference scenario is different from zero, which gives an indication that the technology has already economic advantages even without a subsidy. The second group shows a higher level of implementation in the SUBS60 and SUBS90 scenarios compared to SUBS30. These are all countries with no implementation of the anaerobic digestion technology in the reference scenario and for which the technology is less attractive in economic terms. The third group, the Netherlands and Malta, follow a smoother adoption path but reach a higher maximum implementation share. Both countries can choose between the community and farm based anaerobic digestion technology (as explained in section 3.3). Contrary to Belgium and Denmark, which have the same choice, the combination of a low implementation share in the reference scenario and a relatively less advantageous cost of the community based anaerobic digestion technology makes the adoption slower. A similar pattern can be observed in the dairy and beef sector.

Table 27 shows the impact of subsidising the mitigation technologies on EU activities. Scenario results show that the production effects of the different subsidy levels are actually negligible. Both the SUBS30 and SUBS60 scenario show virtually no impact on area, herd size and supply in the EU-27. Only at a subsidy level of 90% some small adjustments are visible at EU-27, mainly in the pig sector, but even there any production increase is still below 0.3%. The main reason for this is the fact that the cost share of the mitigation technologies in the total cost of production of the agricultural activities is rather low, except for the anaerobic digestion plants in the pig sector. The subsidy is only a fraction of this and therefore, the incentive to change the activity levels is very low. A second reason is related to the maximum implementation levels of the mitigation technologies of "anaerobic digestion". They vary between 0 and 1, and are country specific, determined in the GAINS system in the light of farm structure information. If the subsidy drives the implementation shares to the technical maximum the incentive may also expand activity level.

The small changes that can be observed outside the pig sector are mainly driven by substitution effects (meat sector) or increased demand for feed (cereals) coming from the pig sector. As a direct consequence of the very small production effects, EU price levels stay also almost the same in the subsidy scenarios.

Table 26: Share of pig fattening at MS level using the technology 'anaerobic digestion plant'* according to the SUBS30, SUBS60 and SUBS90 scenarios (%)

	REF	SUBS30	SUBS60	SUBS90	Maximum share**
Austria	6	6	6	6	6
Belgium-Lux	0	72	93	93	93
Denmark	39	84	84	84	84
Finland	0	0	0	0	0
France	5	49	49	49	49
Germany	10	35	35	35	35
Greece	0	20	40	40	40
Ireland	0	77	77	77	77
Italy	0	26	52	52	52
Netherlands	7	57	67	97	100
Portugal	0	15	31	31	31
Spain	0	20	41	41	41
Sweden	2	31	31	31	31
UK	4	23	23	23	23
Bulgaria	0	11	23	23	23
Cyprus	0	23	46	46	46
Czech Republic	0	23	45	45	45
Estonia	0	17	33	33	33
Hungary	0	17	34	34	34
Latvia	0	11	22	22	22
Lithuania	0	16	32	32	32
Malta	0	32	74	100	100
Poland	0	8	16	16	16
Romania	0	23	45	45	45
Slovak Republic	0	16	32	32	32
Slovenia	0	18	36	36	79

* anaerobic digestion includes farm or community based anaerobic digestion plants, or a combination of both

** maximum share means the maximum level of implementation of a mitigation technology by country, based on GAINS

Table 27: Change in area, herd size and supply for the EU-27 for activity aggregates according to the SUBS30, SUBS60 and SUBS90 scenarios

	REF		SUBS30		SUBS60		SUBS90	
	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 ha or t	% difference to REF					
Utilized agricultural area	181,693	na	0.00	na	0.00	na	0.00	na
Cereals	52,856	320,148	0.00	0.00	0.01	0.01	0.11	0.10
Oilseeds	11,856	34,291	0.00	0.00	0.00	0.00	0.06	0.06
Other arable crops	5,783	164,260	0.00	na	0.00	na	0.00	na
Vegetables and perm. crops	25,060	130,747	0.00	na	0.00	na	0.00	na
Fodder activities	77,391	33,378	0.00	0.01	0.00	0.02	-0.01	-0.01
Set aside and fallow land	8,746	na	-0.01	na	-0.06	na	-0.61	na
Dairy cows	21,722	160,509	0.00	0.00	0.00	0.00	-0.01	0.00
Beef meat activities	18,213	7,992	0.00	0.00	-0.01	0.00	-0.05	-0.03
Pig fattening	252,970	23,494	0.06	0.05	0.17	0.15	0.28	0.25
Pig breeding	15,037	259,528	0.05	0.06	0.15	0.17	0.27	0.28
Milk ewes and goat	74,090	5,141	0.00	0.00	-0.01	-0.01	-0.06	-0.04
Sheep and goat fattening	48,548	742	0.00	0.00	-0.01	-0.01	-0.05	-0.05
Laying hens	459	7,776	0.00	0.00	-0.01	-0.01	-0.02	-0.02
Poultry fattening	6,703	13,518	0.00	0.00	-0.01	-0.01	-0.03	-0.03

Note: na = not applicable; total supply of beef includes beef from dairy cows and calves; the reader should be aware that the degree of precision shown in this table is only to illustrate the (very small) differences between activities at EU level, not the accuracy of the model

Looking in more detail at the pig sector, some differentiation can be observed among the EU Member States (Table 28). France and Ireland increase their pork production by 1.9% and 2.2% in the SUBS90 scenario, while others do not change or even decrease their production. The unit benefit of using an anaerobic digestion plant is among the highest for both France and Ireland according to the GAINS data. Only the UK has a higher benefit, but the maximum implementation levels in the UK are limiting the uptake of this technology and consequently limit the use of the subsidy scheme.

Table 28: Change in pig herd size and pig meat production per EU Member State for all subsidy scenarios

	REF		SUBS30		SUBS60		SUBS90	
	Herd size	Prod.	Herd	Prod.	Herd	Prod.	Herd	Prod.
	[1000 hds]	[1000 t]	% difference to REF					
EU-27	252,970	24,287	0.1	0.0	0.2	0.1	0.3	0.3
Austria	5,033	561	-0.1	-0.1	-0.3	-0.3	-0.5	-0.4
Belgium-Lux	10,945	1,146	0.0	0.0	0.1	0.1	0.3	0.3
Denmark	24,729	1,946	0.1	0.1	0.1	0.1	0.1	0.1
Finland	1,903	177	-0.1	-0.1	-0.3	-0.3	-0.5	-0.5
France	26,539	2,530	0.5	0.5	1.2	1.2	1.9	1.9
Germany	49,659	5,424	-0.1	0.0	-0.2	-0.2	-0.4	-0.4
Greece	1,524	104	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2
Ireland	3,524	265	0.6	0.6	1.4	1.4	2.2	2.2
Italy	13,358	1,794	-0.1	-0.1	0.0	0.0	0.0	0.0
Netherlands	20,006	1,582	0.0	0.0	0.0	0.0	0.1	0.1
Portugal	5,517	369	0.0	0.0	0.0	0.0	0.1	0.1
Spain	44,276	3,961	0.0	0.0	0.2	0.2	0.5	0.5
Sweden	2,407	241	-0.1	-0.1	-0.2	-0.2	-0.4	-0.4
UK	8,452	682	0.2	0.2	0.3	0.3	0.5	0.5
EU-15	217,873	20,782	0.1	0.1	0.2	0.2	0.3	0.3
Bulgaria	700	60	0.0	0.0	0.0	0.0	0.0	0.0
Cyprus	796	69	0.0	0.0	0.2	0.2	0.5	0.5
Czech Republic	2,848	297	0.0	0.0	-0.1	-0.1	-0.2	-0.2
Estonia	693	62	0.0	0.0	-0.2	-0.2	-0.3	-0.3
Hungary	3,220	376	0.0	0.0	0.2	0.2	0.5	0.4
Latvia	699	68	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Lithuania	1,273	111	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Malta	83	8	0.0	0.0	0.2	0.3	0.5	0.5
Poland	20,095	1,962	0.0	0.0	0.0	0.0	0.0	0.0
Romania	3,777	384	0.0	0.0	0.0	0.0	0.0	0.0
Slovak Republic	618	65	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Slovenia	295	43	0.0	0.0	0.3	0.3	0.7	0.7
EU-N12	35,097	3,506	0.0	0.0	0.0	0.0	0.0	0.0

7 Effects of introducing emission leakage into the scenario analysis

The GHG mitigation policy scenarios with a reduction target all show an impact on agricultural production in the EU. The changed production in the EU influences prices, production and trade also in other regions of the world, which may also affect global GHG emissions. This implies that any GHG emission reduction achievement in the EU could be diminished in terms of its global impact due to a shift of production outside the EU implying emission leakage, i.e. a shift in GHG emissions from the EU to the rest of the world. In this section we try to quantify the possible emission leakage effects that may be associated with GHG emission reduction commitments in the EU.

7.1 Methodology: Estimation of GHG emission leakage in the policy scenarios

The emission module of CAPRI is based on technical information from the supply model (see chapter 3). Since this information is only available for the EU member states in the model (supply curves for other world regions are mainly based on products and prices and not on a detailed modelling of farming activities), CAPRI does not regularly provide emission estimates for non-EU countries. This is a major drawback for the analysis of the total emission impacts in policy scenarios since emission reductions in the EU linked to production decreases might trigger emission increases outside the EU if the EU production decreases are compensated by increases of imports or decreases of exports. This could considerably reduce or even inverse the net impact of EU policy measures on total emissions. To provide at least a rough estimate on emission impacts outside the EU, in the course of the CAPRI-ECC project[17] a module was developed which estimates emission factors of agricultural products for non-EU countries. The module uses emission coefficients of EU countries as prior information (taken from the CAPRI model) and changes those factors in order to be consistent with total emission estimates for non-EU countries taken from the EDGAR database, applying a Bayesian estimation framework. For a more detailed description of the methodology see Jansson et al. (2010) and Pérez Dominguez et al. (2012). Those emission factors (per kg of product) are then applied to production quantities, a regular model-output for all world regions, in order to estimate total world emissions of the agricultural sector.

There are several limitations of the existing emission leakage module, which are partly linked to the methodology and partly to data limitations in CAPRI. First of all, the methodology allowed only emission estimates for emission categories available in the EDGAR database and allocated explicitly to the agricultural sector. The module, therefore, considered only emissions of the category 'agriculture' (CRF Sector 4) of the UNFCCC inventories. By contrast, emissions from energy use, transport or land use change could not be allocated in the module. This was a drawback especially with respect to emissions from land use change which could be one of the major non-EU emission sources affected by agricultural activities in the EU.

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[17] “Development of Quantitative Tools for the Economic Analysis of Greenhouse Gas Emissions in Agriculture” (Contract IPTS No 151467-2009 A08/NL); see Pérez Dominguez et al. (2012).

Second, since the methodology assigns emission coefficients to different products in a way that the total production multiplied with the coefficients equals the total emissions in the EDGAR database, emissions from intermediate products (like soybeans fed to animals) risk to be underestimated or double counted. In order to avoid this problem, feed and crop products have been strictly separated, and only if 100% is fed to animals the emissions are allocated to animal products. Emissions from marketable feeds are, therefore, not assigned to animal products, but to the marketable crop. Finally, processed products, like soybean meal, are not included in the analysis. As a consequence of these limitations in the CAPRI emission leakage module, product-emissions for non-EU countries cannot be interpreted as LCA-like emission factors[18] and are not comparable to LCA-factors calculated for EU Member States.

One of the objectives of the EcAMPA study was the inclusion of emissions from land use change in the analysis of emission leakage. For reasons explained above we could not use the same methodology as for the other gas emissions. However, in the GGELS project[19] land use change emission factors from land cropland expansion have been calculated for CAPRI. These factors are based on FAO crop statistics for 1999-2008 (FAO, 2010), IPCC 2006 guidelines (IPCC, 2006) and land cover and soil maps from Carre et al. (2009), and they allocate emissions from net increases of cropped area proportionally to the crops with area growth (see Leip et al., 2010). Within the EcAMPA project these land use change emission factors have now been implemented directly in the emission leakage module of CAPRI. By contrast, land use change emission factors from pasture expansion are not available on the same level of detail and, therefore, have not been considered in the present estimation. Similarly, all other types of land use change effects which might be related to agricultural activities (i.e. pasture or cropland transformation to forest) are not taken into account. The emission factors for crop related land use change from the GGELS project are provided for three scenarios, one worst case scenario (with most new cropland coming from forest wherever forest is available and deforestation cannot be excluded), one best case scenario (all new cropland coming from former grassland), and one scenario with “more likely” shares. The assumed shares for the “worst case” and the “more likely” scenarios are shown in Table 29. They are not based on statistical data and should be considered as storylines which should rather cover the range of possible outcomes than pretend to give exact information (which is not available for most countries). All emission factors for land use change emissions are fixed and based on past observations. There is currently no dynamic land use model implemented in CAPRI for non-EU countries.

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[18] LCA = Life Cycle Assessment (for further information see e.g. Leip et al., 2010).

[19] “Evaluation of the livestock sector’s contribution to the EU greenhouse gas emissions (GGELS)” (AA AGRI-2008-0245 and AA AGRI-2009-0296); see Leip et al. (2010).

Table 29: Scenarios for the transformation of land use categories to cropland (in percent of one ha new cropland)[20]

Scenario	Country	Grassland	Shrubland	Forests less than 30% canopy cover	Forests above 30% canopy cover
More likely	Europe (EU and non-EU)	100	0	0	0
	Canada, Russia and former Soviet countries, Australia and New Zealand	20	20	20	40
	India, Mexico, Morocco, other non-European Mediterranean countries	50	50	0	0
	Argentina, Uruguay, Paraguay, Bolivia, Least Developed Countries (incl. ACP)	50	40	10	0
	Brazil, Venezuela, Rest of South America, all other world regions with cropland increases	50	20	20	10
Worst case	Europe (EU and non-EU)	100	0	0	0
	Russia and former Soviet countries, Australia and New Zealand, Canada, Mexico, Venezuela, Brazil, Paraguay, Bolivia, Rest of South America, India, Least Developed Countries (incl. ACP)	0	0	0	100
	Argentina, all other world regions with cropland increases	25	25	0	50
	Uruguay	50	25	0	25
	Morocco, other non-European Mediterranean countries	50	50	0	0

Emission sources not considered in the agricultural sectors according to the UNFCCC but included in "emissions related to agriculture" for the analysis of emission leakage are presented in Table 30.

Table 30: Emission sources considered in “emissions related to agriculture” but not in “agricultural emissions” for the analysis of emission leakage

GHG	UNFCCC Sector	CAPRI reporting and emission source	
CH_4	Land use and land use change	CH4BUR	Biomass burning
N_2O	Land use and land use change	N2OBUR	Biomass burning
	Land use and land use change	N2OSOI	Nitrogen losses from soils
	Industrial processes	N2OPRD	Mineral fertilizer production
CO_2	Land use and land use change	CO2BIO	Above and below ground biomass and dead organic matter
	Land use and land use change	CO2SOI	Losses of soil organic carbon
	Land use and land use change	CO2HIS	Cultivation of organic soils
	Energy	CO2PRD	Mineral fertilizer production

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[20] The factors in Table 29 are only applied to world regions/countries with cropland increases from 1999-2008. A couple of regions like the USA, China and Japan registered cropland losses instead and, therefore, no emissions from land use change are assigned to those countries. In Europe cropland increased in Germany, Ireland, Finland, United Kingdom, Estonia, Hungary, Latvia, Slovenia, Slovakia, Norway, Bosnia and Herzegovina.

For the understanding of the emission leakage dynamics we are mainly interested in emission changes related to trade und production. Therefore we decompose the changes of total emissions (ΔE) in those related to the change of emission factors (ΔE^b) and those related to production changes (ΔE^a).

$$\Delta E^a = (X^{Scen} - X^{Base}) * \ EF^{Base}$$

$$\Delta E^b = (EF^{Scen} - EF^{Base}) * X^{Scen}$$

$$\Delta E = X^{Scen} * EF^{Scen} - X^{Base} * EF^{Base} = \Delta E^a + \Delta E^b$$

X: Production, EF: emission factors, Base: base scenario, Scen: Alternative scenario

In the EcAMPA study we introduced technical GHG mitigation measures for EU agriculture (see chapter 3). Consequently, within the EU, changes of the emission factors can be due to applied mitigation technologies, shifts of the production intensity or due to a shift of the production among different regions. By contrast, for non-EU countries neither specific mitigation technologies nor shifts in the production intensity are considered. Therefore, changes of emission factors in the emission leakage module are always due to regional composition effects related to shifts of production among country blocks. ΔE^b for the non-EU world indicates also how much the numbers might change if we used unique emission factors for all imported goods (to the EU) instead of country block specific ones.

7.2 Results: Impacts of the policy scenarios on emission leakage and global emissions

Small share of EU in total world agricultural emissions

The EU accounted for 9.2% of total world agricultural emissions in the base year 2005 according to the CAPRI emission accounting. In the reference scenario for 2030 this share declines to 6.8%, mainly due to stronger population dynamics and changing diets outside Europe. Considering also emissions from land use change and fertilizer production (which are not accounted in the agricultural sector according to the UNFCCC framework), as far as they are related to agricultural production, these shares are further reduced to 5.2%-8.3% (2005) and 3.7%-6.1% (2030). Total world agricultural emissions are projected to increase by around 32% from 2005 to 2030, total emissions related to agriculture even by 35-37%. As a result, the modelled mitigation achievements in the EU agricultural sector of 19-28% would reduce world emissions by 1.3%-1.9% (agricultural sector) or 0.7%-1.7% (emissions related to agriculture) if emission leakage is not taken into account.

Most of mitigation achievements lost via emission leakage in emission target scenarios

For those scenarios imposing emission reduction targets (HOM19, HOM19ET, HOM28, HOM28ET, HET19, HET28) mitigation achievements in the EU might be mainly offset by the emissions prompted by additional production outside the EU. So, according to CAPRI simulations, none of the mitigation scenarios leads to a net reduction of total world emissions from the agricultural sector compared to the reference scenario of more than 0.5% (see Table 31). Interestingly, higher emission targets do might not lead to higher world net mitigation, because EU Member States first tend to exhaust options to reduce emission intensities, while further reductions are achieved via production cuts. However, as analysed in previous chapters, scenario results show that the production declines in the EU are not accompanied by equivalent decreases in consumption. At least part of the EU production decrease might just be replaced by imports, which causes emissions outside the EU. The share of mitigated emissions neutralized by emission leakage ranges between 64% (HOM19ET) and 91% (HET28). As a consequence, the net mitigation might not exceed 9%-36% of the emission mitigation achievements in the EU (see Table 32) given the assumptions made.

Splitting total emission effects (ΔE) into a part related to production changes (ΔE^a) and a part related to changes in the emission factors (ΔE^b) shows that for all scenarios with emission targets reduced production in the EU creates even higher emissions outside the EU (see Table 33). The net production effect ranges from 0.9% (HOM19) to 3.5% (HET28) emission increases, while net mitigation is only achieved via the reduction of emission intensity (between -6% (HET19) and -8.3% (HOM28ET)). Table 34 indicates how much emissions outside the EU could rise if emissions in the EU would be reduced by one unit of CO_2-equivalent achieved by production decreases (ΔE^a), assuming unchanged consumer preferences. The factors range from 1.4 to 1.6 for agricultural emissions – but the factors could considerably increase if we include also emissions related to agriculture, like land use change, into the analysis.

Scenarios with subsidies with lower mitigation effects and negligible leakage effects

In contrast to the scenarios with mitigation targets, the subsidy scenarios (SUBS30, SUBS60, SUBS90), do not lose mitigation achievements via emission leakage. Table 33 shows even small negative leakage effects. This is because in the SUB scenarios mitigation is achieved via reduced emission intensities rather than decreased EU production, and hence no additional imports are triggered. The emission effects related to decreases in production (ΔE^a) and emission intensities (ΔE^b) , presented in Table 33, show zero values for production effects and emission intensity effects between 0.6%-4.5% of total EU agricultural emissions in the reference scenario both on the EU level and world level. By contrast, the scenarios with mitigation targets show high performance on EU level, with roughly 50% shares of production and emission intensity effects. However, the considerable impact on global production (due to additional EU imports) may trigger not only emissions from production increases outside the EU but also increase the emission factors (due to a relocation of production), leading to a neutralization of EU mitigation achievements to a higher degree than ΔE^a in the EU would suggest.

Homogeneous emission targets with lower emission leakage

Among the scenarios with emission mitigation targets, a homogeneous distribution of emission targets among Member States leads to lower leakage shares than a heterogeneous distribution (see Table 32). This can be explained by relatively lower production effects for homogeneous emission target scenarios (Table 33). In HET19 the production effect accounts for 9.8% compared to 9.1% in HOM19, whereas emission intensity reduction is responsible for 9.3% (HET19) and 9.8% (HOM19) of emission mitigation. Similarly, ΔE^a is 15.3% in HOM28 and 16.1% in HET28, while $\Delta E^b$is 12.6% (HOM28) and 12.4% (HET28).

The higher the emission target the higher the share of emission leakage

It was already mentioned above that higher emission targets do not necessarily lead to higher net world mitigation achievements (see Table 32) since measures targeting the reduction of emission intensities (technical mitigation measures and relocation of production inside the EU) are applied first, while higher targets are mainly achieved via production cuts. This is also reflected in the numbers presented in Table 33. While ΔE^{b} may increase only from 9.3% to 12.4% in HET19 compared to HET28, ΔE^{a} increases from 9.8% to 16.1%. For HOM19 and HOM28 the numbers are similar: 9.1% to 15.3% (ΔE^{a}) and 9.8% to 12.6% (ΔE^{b}).This effect, however, might be driven by the limited number of technical abatement options considered in this study.

Emission trading generally dampens leakage

Given the uncertainties and the assumptions on transaction costs, emission trading might lead to a more efficient use of mitigation potentials via a reduction of emission intensities. Therefore, ΔE^{b} is generally higher and ΔE^{a} is lower than in the comparable scenarios without emission trading, which dampens the effect of emission leakage (see Table 32). The production effect ΔE^{a} shrinks from 9.1% to 8.6% (HOM19 to HOM19ET) and 15.3% to 14.4% (HOM28 to HOM28ET), while ΔE^{b} increases from 9.8% to 10.3% and 12.6% to 13.5% respectively Table 33.

Including land use change emissions reduces net mitigation gains

Considering the extended set of emissions related to agricultural production (especially emissions from land use change due to the expansion of agricultural land) the mitigation effect in the EU may be almost completely neutralized by additional emissions outside the EU for all scenarios imposing emission targets (see Table 31). Scenarios with a higher emission target (HOM28, HET28 and HOM28ET) may result even in a slight net increase of world emissions. Net world emission changes for the more likely land use change storyline, relative to total EU emissions in the reference scenario, may range from -1.6% (HOM19et) to +4% (HET28 and HOM28), as indicated in Table 33. For the reasons mentioned above homogeneously distributed emission targets achieve slightly better net effects than heterogeneously distributed emission targets (0%-0.5%), and emission trading also improves the performance by 0.6%-2.2% (of total EU emissions in the reference year). There is, however, large uncertainty about the values, on the one hand, because we assume constant LUC-factors, as explained in the methodological part, on the other hand, because we do not know the details of the land use transition matrix. The latter is represented in our analysis with lower and upper bounds of LUC emissions. Those bounds are presented in Table 33 and show uncertainty ranges of 8.4% to 17.6% of EU total emissions. Land use change emissions might be underestimated because we only consider land transformation to cropland but not to pastures (due to a lack of reliable data). The FAO has published estimates on luc-factors from pasture expansion for beef from some South American countries (McLeod et al., 2013; Opio et al., 2013). The values[21] range from 0 to 181.4 kg CO_2eq/kg of beef, assuming 100% of new pasture area coming from former forests. Applying the average value for Middle and South America (31.7 kg CO_2eq/kg of beef) to beef production from Africa, Middle and South

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[21] Provided by FAO via personal contact.

America (no values for Africa available from FAO) would increase world emissions related to agriculture by around 10%. Emission leakage for the mitigation scenarios would rise by another 4.3-9.3% relative to total EU emissions in the reference scenario. In contrast, the reduced agricultural production in the EU might lead to an expansion of forest areas on expense of cropland or grassland, which could dampen emissions since more carbon would be sequestrated than in the reference scenario.

Table 31: Total emissions relative to the reference scenario (%)

		REF	HET19	HET28	HOM19	HOM19ET	HOM28	HOM28ET	SUBS30	SUBS60	SUBS90
Agricultural emissions	EU-27	100.0	80.9	71.5	81.1	81.1	72.1	72.1	99.4	98.0	95.5
	World	100.0	99.7	99.8	99.6	99.5	99.6	99.6	100.0	99.9	99.7
Emissions related to agriculture*	EU-27	100.0	83.3	74.7	83.3	83.5	74.9	74.9	99.6	98.5	96.6
	World	100.0	100.0	100.2	99.9	99.9	100.2	100.1	100.0	99.9	99.8

* Land use change emissions based on the "more likely” case (see Table 29

Table 32: Share of emission reduction in the EU that may be neutralized by emission leakage (%)

		HET19	HET28	HOM19	HOM19ET	HOM28	HOM28ET	SUBS30	SUBS60	SUBS90
Agricultural emissions	Net emission reduction	23	9	33	36	19	23	102	101	101
	Emission leakage	77	91	67	64	81	77	-2	-1	-1

Table 33: Split of emission changes by production effects and effects related to changed emission factors (relative to total emissions in the reference scenario (%)

				HET19	HET28	HOM19	HOM19ET	HOM28	HOM28ET	SUBS30	SUBS60	SUBS90
Agricultural emissions	EU-27		ΔE^a	-9.8	-16.1	-9.1	-8.6	-15.3	-14.4	0.0	0.0	0.0
			ΔE^b	-9.3	-12.4	-9.8	-10.3	-12.6	-13.5	-0.6	-2.0	-4.5
	Non-EU		ΔE^a	11.4	19.6	9.9	9.4	17.4	16.4	0.0	0.0	0.0
			ΔE^b	3.3	6.2	2.7	2.6	5.3	5.1	0.0	0.0	0.0
	World		ΔE^a	1.6	3.5	0.9	0.9	2.1	2.1	0.0	0.0	0.0
			ΔE^b	-6.0	-6.2	-7.1	-7.7	-7.3	-8.3	-0.6	-2.0	-4.5
	EU-27		ΔE	-19.1	-28.5	-18.9	-18.8	-27.9	-27.8	-0.6	-2.0	-4.5
	Non-EU			14.8	25.8	12.6	12.1	22.6	21.6	0.0	0.0	0.0
	World			-4.3	-2.7	-6.3	-6.8	-5.3	-6.3	-0.6	-2.0	-4.5
Emissions related to agriculture	EU-27	Lo/Ml/Up	ΔE^a	-8.7	-14.4	-8.2	-7.7	-14.0	-13.1	0.0	0.0	0.0
			ΔE^b	-8.0	-10.9	-8.4	-8.8	-11.0	-12.0	-0.4	-1.5	-3.4
	Non-EU	Lo	ΔE^a	11.1	19.5	10.3	9.7	18.5	17.2	0.0	0.0	-0.1
			ΔE^b	3.2	6.1	2.9	2.8	5.7	5.4	0.0	0.0	0.0
		Ml	ΔE^a	12.4	22.1	11.9	11.3	21.8	20.1	0.0	0.0	-0.1
			ΔE^b	3.8	7.2	3.7	3.6	7.3	6.9	0.0	0.0	0.0
		Up	ΔE^a	15.7	28.7	15.6	14.8	29.5	26.9	0.0	0.0	-0.1
			ΔE^b	5.9	11.3	6.3	6.1	12.3	11.4	0.0	0.0	0.0
	World	Lo	ΔE^a	2.4	5.1	2.1	2.0	4.5	4.1	0.0	0.0	0.0
			ΔE^b	-4.8	-4.8	-5.5	-6.0	-5.3	-6.0	-0.4	-1.5	-3.5
		Ml	ΔE^a	3.7	7.7	3.7	3.6	7.8	7.0	0.0	0.0	0.0
			ΔE^b	-4.2	-3.7	-4.7	-5.2	-3.7	-5.2	-0.4	-1.5	-3.5
		Up	ΔE^a	7.0	14.3	7.4	7.1	15.5	13.9	0.0	0.0	-0.1
			ΔE^b	-2.1	0.5	-2.1	-2.7	1.2	-0.6	-0.4	-1.5	-3.5
	EU-27	Lo	ΔE	-16.7	-25.3	-16.6	-16.5	-25.0	-25.1	-0.4	-1.5	-3.4
	Non-EU			14.4	25.6	13.2	12.6	24.2	22.6	0.0	0.0	-0.1
	World			-2.3	0.3	-3.5	-3.9	-0.9	-2.5	-0.4	-1.5	-3.5
	EU-27	Ml		-16.7	-25.3	-16.6	-16.5	-25.0	-25.1	-0.4	-1.5	-3.4
	Non-EU			16.2	29.3	15.6	14.9	29.1	26.9	0.0	0.0	-0.1
	World			-0.5	4.0	-1.0	-1.6	4.0	1.8	-0.4	-1.5	-3.5
	EU-27	Up		-16.7	-25.3	-16.6	-16.5	-25.0	-25.1	-0.4	-1.5	-3.4
	Non-EU			21.6	40.1	21.9	20.9	41.8	38.3	0.0	0.0	-0.2
	World			4.9	14.8	5.3	4.4	16.7	13.2	-0.4	-1.5	-3.6

Land use change scenarios: Lo: Lower limit, Ml: Most likely scenario, Up: Upper limit

Table 34: Share of emissions outside the EU caused by emission reduction from production decreases inside the EU (%)

			HET19	HET28	HOM19	HOM19ET	HOM28	HOM28ET
Agricultural emissions	$(\Delta E^a+\Delta E^b)_{\text{Non-EU}} / \Delta E^a_{\text{EU}}$		151	161	139	141	148	150
Emissions related to agriculture		Lo	165	177	161	163	173	173
		Ml	186	203	191	193	208	206
		Up	248	278	267	271	299	293

Land use change scenarios: Lo: Lower limit, Ml: More likely scenario, Up: Upper limit

Import of animal products causes major part of emission leakage

Table 37 shows that beef and other animal products could be responsible for more than 90% of additional emissions outside the EU in all scenarios if we consider agricultural emissions. This is also reflected in the dominating emission sources, which is N_2O-emissions from grazing animals and methane emissions from enteric fermentation and manure management (see Table 36). If considering land use change emissions, some cereals, like maize and wheat, get an increasing share, which is, however, partly due to the fact that marketable feeds are not assigned to animal products, as explained in the methodological section. Therefore, part of these emissions are actually triggered by the production of animal products. In terms of emission sources, the major part of land use change emissions may come from above and below ground biomass (CO2BIO), depending on the share of agricultural area on recently deforested land (see difference between the lower and upper limit in Table 36). As a result of the lower animal production in the EU, emissions from soybean imports in some scenarios (HOM19, HET19, HOM19ET) are slightly lower than in the reference scenario. The decline of EU soybean imports may also be accompanied by a re-location from South America to North America, reducing emissions from land use change. However, to a large extent, feed imports are rather increasing in the scenarios, while EU feed production is on the decline. As a consequence emissions from wheat and maize imports may go up, and so may emissions from soybean imports in the scenarios with higher emission reduction targets.

More than one third of emission leakage due to additional imports from Africa

The overwhelming part of emission increases outside the EU, according to CAPRI projections, may happen in African countries (38.8%-57.8%), followed by Asia (12.3%-16.8%) and South America (11.6%-19.2%). Taking into account emissions from land use change generally decreases the African, and increases the South American share (see Table 35), due to higher luc-factors in South America. Additional wheat imports may mainly come from other European countries (outside the EU) and North America, maize imports predominantly from North and South America. Therefore, with both similar import increases and similar additional emissions from the agricultural sector, land use change emissions might be affected much stronger from maize imports than from wheat imports (see Table 37).

Conclusions and limitations of the emission leakage approach

The analysis on emission leakage reveals that policies imposing emission mitigation targets, while strongly impacting on EU production, might not achieve emission reduction targets on the global level since mitigated emissions may possibly be neutralised by emission leakage. The results suggest that incentives impacting on emission intensities might achieve similar net effects, disturbing markets considerably less. The subsidies for technological mitigation measures alone are likely, however, to be insufficient to achieve emission reduction targets of 20-30%. Land use change emissions have been included in the analysis for emission leakage, using an approach with strong limitations: Emission factors are supposed to be constant per product and CAPRI region, which means that technological changes (mitigation measures, productivity changes etc.) outside the EU and indirect effects of intensity changes and area re-allocations that go along with the production changes in non-EU regions are ignored. This might favour a slight overestimation of the emission leakage effect. Moreover, due to a lack of reliable data, we consider only luc-emissions related to cropland expansion, while other forms of land use changes, like pasture expansion, have been ignored. Results should, therefore, be considered as indicative and further research will be necessary in order to reduce the large amount of uncertainties with respect to emission leakage.

Table 35: Shares of world regions in emission increases outside the EU (%)

	HET19			HET28			HOM19			HOM19ET			HOM28			HOM28ET		
	Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture	
		Lo	Up		Lo	Up		Lo	Up		Lo	Up		Lo	Up		Lo	Up
Russia	3.2	4.7	5.7	2.5	4.4	5.8	3.6	6.9	9.0	3.7	6.8	8.7	2.7	6.3	8.6	2.8	6.0	8.1
Middle East	1.2	2.0	2.2	1.1	1.9	2.1	1.3	2.2	2.3	1.3	2.2	2.3	1.2	2.1	2.1	1.2	2.1	2.1
South Africa	5.3	4.4	2.9	6.2	5.0	3.2	5.0	3.8	2.3	5.0	3.8	2.3	5.8	4.4	2.5	5.9	4.5	2.6
Africa LDC	13.1	14.3	18.6	14.1	15.0	18.6	12.3	13.8	18.2	12.3	13.9	18.3	13.7	14.7	18.3	13.8	14.8	18.4
Africa others	37.1	30.1	20.4	35.9	28.6	18.6	36.0	27.3	16.9	36.6	27.8	17.1	35.6	26.4	15.7	36.4	27.4	16.5
India	5.5	4.8	3.5	6.5	5.6	3.9	5.4	4.5	2.8	5.2	4.3	2.7	6.3	5.1	3.2	6.1	5.0	3.2
China	4.8	4.1	2.8	4.5	3.8	2.4	5.3	4.2	2.5	5.2	4.2	2.5	4.9	3.8	2.2	4.8	3.8	2.3
Indonesia	1.3	1.8	1.4	1.2	1.7	1.2	1.4	1.8	1.3	1.4	1.7	1.2	1.3	1.7	1.1	1.2	1.6	1.1
USA	6.0	5.6	3.7	5.9	5.4	3.5	6.5	5.7	3.4	5.8	5.2	3.1	6.2	5.4	3.1	5.6	5.0	2.9
Argentine	3.8	3.4	1.8	3.2	3.2	2.0	4.0	3.2	0.4	4.1	3.3	0.6	3.4	3.1	1.1	3.5	3.3	1.5
Brazil	6.5	8.1	14.1	6.4	8.4	15.3	6.9	8.6	14.6	7.2	8.9	14.7	6.6	8.8	15.7	6.8	8.9	15.5
Rest of South America	1.2	1.5	1.5	1.2	1.4	1.5	1.3	1.5	1.5	1.2	1.4	1.4	1.2	1.5	1.4	1.2	1.4	1.3
Europe (Non EU)	6.1	9.7	13.4	5.0	9.3	13.6	7.0	13.7	20.5	7.0	13.6	20.3	5.6	13.0	20.2	5.5	12.2	19.0
Asia	16.1	16.8	14.1	16.7	17.2	13.9	16.2	16.4	12.8	15.8	16.0	12.4	16.5	16.4	12.4	16.0	16.1	12.3
Africa	56.9	50.6	44.4	58.2	50.8	43.0	54.6	46.5	39.5	55.3	47.1	39.9	56.9	47.4	38.8	57.8	48.7	39.8
North America	7.7	7.9	7.5	7.6	7.9	7.7	8.4	8.2	7.5	7.7	7.8	7.5	8.2	8.0	7.2	7.4	7.5	7.3
Middle and South America	12.3	13.7	17.9	11.6	13.8	19.2	13.0	14.0	16.9	13.3	14.2	17.0	12.0	14.1	18.7	12.3	14.2	18.8
Non-EU	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*

Table 36: Shares of emission sources in emission increases outside the EU (%)

	HET19			HET28			HOM19			HOM19ET			HOM28			HOM28ET		
	Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture	
		Lo	Up		Lo	Up		Lo	Up		Lo	Up		Lo	Up		Lo	Up
N2OAPP	2.8	2.2	1.5	2.6	2.0	1.3	2.8	2.1	1.3	2.6	1.9	1.2	2.6	1.9	1.1	2.4	1.8	1.1
N2OGRA	30.0	23.8	15.9	30.3	23.5	15.0	29.0	21.4	12.9	29.3	21.7	13.0	29.6	21.4	12.4	30.0	22.1	13.0
N2OSYN	4.9	3.9	2.6	5.1	4.0	2.5	5.8	4.3	2.6	5.7	4.2	2.5	5.9	4.2	2.4	5.6	4.1	2.4
N2OHIS	0.7	0.5	0.3	0.7	0.6	0.4	0.9	0.6	0.4	0.9	0.6	0.4	0.9	0.7	0.4	0.9	0.6	0.4
N2OCRO	2.6	2.1	1.4	2.8	2.1	1.4	2.9	2.1	1.3	2.9	2.2	1.3	3.0	2.2	1.3	3.0	2.2	1.3
N2OLEA	1.1	0.9	0.6	1.1	0.9	0.6	1.2	0.9	0.5	1.2	0.9	0.5	1.2	0.9	0.5	1.2	0.9	0.5
N2OAMM	1.9	1.5	1.0	1.8	1.4	0.9	2.0	1.5	0.9	1.9	1.4	0.8	1.9	1.4	0.8	1.8	1.3	0.8
N2OPRD		2.3	1.5		2.3	1.5		2.5	1.5		2.5	1.5		2.5	1.4		2.4	1.4
N2OBUR		0.0	0.1		0.0	0.1		0.0	0.1		0.0	0.1		0.0	0.1		0.0	0.1
N2OMAN	2.6	2.1	1.4	2.5	1.9	1.2	2.7	2.0	1.2	2.5	1.9	1.1	2.5	1.8	1.0	2.3	1.7	1.0
CH4ENT	47.4	37.7	25.1	47.5	37.0	23.6	46.6	34.4	20.7	47.3	35.0	21.0	46.6	33.7	19.5	47.4	34.9	20.6
CH4MAN	4.6	3.6	2.4	4.3	3.3	2.1	4.7	3.5	2.1	4.3	3.2	1.9	4.3	3.1	1.8	4.0	2.9	1.7
CH4RIC	1.4	1.1	0.7	1.4	1.1	0.7	1.5	1.1	0.7	1.4	1.0	0.6	1.4	1.0	0.6	1.3	1.0	0.6
CH4BUR		0.0	0.2		0.0	0.2		0.0	0.2		0.0	0.2		0.0	0.2		0.0	0.2
N2OSOI		0.9	0.6		1.0	0.7		1.2	0.8		1.2	0.8		1.3	0.9		1.2	0.8
CO2PRD		2.5	1.7		2.5	1.6		2.7	1.6		2.7	1.6		2.7	1.6		2.6	1.6
CO2BIO		2.7	34.4		3.0	37.0		3.5	40.6		3.5	40.6		3.8	42.9		3.6	41.7
CO2SOI		8.2	6.1		9.2	6.5		11.4	7.8		11.3	7.8		12.4	8.2		11.7	7.9
CO2HIS		4.0	2.6		4.3	2.7		4.8	2.9		4.8	2.9		5.1	2.9		4.9	2.9
GWP of agricultural emissions	*141.8*	*100.0*	*100.0*	*147.2*	*100.0*	*100.0*	*160.5*	*100.0*	*100.0*	*160.3*	*100.0*	*100.0*	*166.4*	*100.0*	*100.0*	*162.0*	*100.0*	*100.0*
GWP from emissions related to agriculture	*100.0*	*79.5*	*52.8*	*100.0*	*77.8*	*49.7*	*100.0*	*73.9*	*44.4*	*100.0*	*74.0*	*44.5*	*100.0*	*72.2*	*41.8*	*100.0*	*73.6*	*43.4*

Table 37: Shares of emission sources (commodities) in emission increases outside the EU (%)

	HET19			HET28			HOM19			HOM19ET			HOM28			HOM28ET		
	Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture		Emissions agriculture	Emissions related to agriculture	
		Lo	Up		Lo	Up		Lo	Up		Lo	Up		Lo	Up		Lo	Up
Rye	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.3	0.2	0.1	0.2	0.2
Barley	0.5	2.3	4.9	0.5	2.3	4.7	0.6	2.8	5.3	0.6	2.8	5.3	0.6	2.7	5.0	0.6	2.6	4.9
Oats	0.1	0.2	0.4	0.1	0.2	0.4	0.1	0.2	0.3	0.1	0.2	0.3	0.1	0.2	0.3	0.1	0.2	0.3
Maize	1.8	8.3	19.8	1.8	8.2	18.8	2.1	9.3	20.4	2.0	9.1	20.0	2.1	9.2	19.4	1.9	8.7	18.7
Other cereals	0.3	1.8	5.5	0.3	1.8	5.1	0.3	2.2	6.0	0.3	2.1	6.0	0.3	2.1	5.4	0.3	1.9	5.3
Rape	0.5	1.1	3.1	0.6	1.6	4.2	0.7	2.9	7.2	0.7	3.0	7.4	0.7	3.2	7.6	0.7	3.0	7.3
Sunflowers	0.1	0.2	0.3	0.1	0.6	1.0	0.4	2.5	4.3	0.5	2.5	4.4	0.5	3.0	5.1	0.5	2.5	4.4
Soybeans	-0.1	-0.6	-1.3	0.1	0.4	1.5	-0.2	-1.3	-2.6	-0.2	-1.2	-2.2	0.0	0.1	1.3	0.1	0.3	1.7
Other pulses	0.0	0.2	0.8	0.0	0.4	1.2	0.0	0.2	0.4	0.0	0.2	0.4	0.0	0.3	0.9	0.0	0.4	1.0
Potatoes	0.1	0.2	0.4	0.1	0.2	0.4	0.1	0.3	0.3	0.1	0.2	0.3	0.1	0.2	0.3	0.1	0.2	0.3
Wheat	1.7	6.6	12.0	1.8	6.8	12.0	2.1	7.8	13.0	2.1	7.8	12.9	2.2	7.7	12.4	2.0	7.5	12.2
Beef	74.5	60.5	40.3	74.6	59.3	37.9	71.8	54.2	32.6	73.4	55.5	33.4	72.2	53.3	30.8	74.0	55.6	32.8
Pork	5.9	4.7	3.1	5.1	4.0	2.5	6.2	4.6	2.8	5.3	3.9	2.3	5.3	3.9	2.2	4.6	3.4	2.0
Sheep and goat meat	3.1	2.6	1.8	3.3	2.7	1.8	3.5	2.7	1.6	4.4	3.5	2.1	3.7	2.9	1.7	4.8	3.7	2.2
Poultry meat	1.1	0.9	0.6	1.0	0.8	0.5	1.1	0.8	0.5	1.0	0.7	0.4	1.0	0.8	0.4	0.9	0.7	0.4
Rice	1.7	2.2	2.2	1.7	2.1	2.0	1.9	2.2	1.9	1.7	2.0	1.7	1.8	2.1	1.7	1.6	1.9	1.6
Sugar	0.2	0.8	0.5	0.2	0.8	0.5	0.2	0.9	0.5	0.2	0.8	0.5	0.2	0.9	0.5	0.2	0.8	0.5
Milk	8.4	7.0	4.7	8.6	7.0	4.5	8.9	6.8	4.1	7.7	5.9	3.5	8.8	6.6	3.8	7.5	5.8	3.4
Animal products	93.1	75.7	50.4	92.6	73.7	47.1	91.5	69.2	41.6	91.7	69.6	41.8	91.1	67.4	39.0	91.7	69.1	40.8
Crop products	6.9	24.3	49.6	7.4	26.3	52.9	8.5	30.8	58.4	8.3	30.4	58.2	8.9	32.6	61.0	8.3	30.9	59.2
Total	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*

8 Concluding remarks

The modelled mitigation policy options show important impacts on agricultural production in the EU-27, especially for the livestock sector and fodder production. Depending on the scenario, results project decreases in the EU beef production between 18% (HOM19ET) and 31% (HET28), and declines in total UAA between 7% (HOM19ET) and 13% (HOM28). Crop production is directly affected by the GHG emissions reduction obligations and indirectly by the reduced demand for feed from the livestock sector. At EU-27 level, cereal production is projected to decrease between 3% (HET19) and 8% (HOM28).

The decrease in EU production, which is not compensated by equal imports, leads to higher producer prices, which more than offsets the income losses provoked by decreases in production and increasing costs in about 90% of the EU regions. It is likely that some farmers might have to leave the sector in case they are not able to cope with the GHG mitigation obligations. Obviously, only farmers remaining in the sector would benefit from the projected increase in total agricultural income. The increased price level means as well that the EU becomes less competitive on the world market and EU exports decline as a result. Consumers will have to pay higher prices for food, especially for meat and dairy products (e.g. consumer prices for beef meat are projected to increase by up to 31%), reflecting the GHG intensity of these products.

Given the restricted assumptions made on the technological and management mitigation options available in 2030, the impact of a change in livestock production management and technology on GHG emissions is rather limited. While the effects of changes in the feed mix on enteric fermentation via digestibility have been included in the analysis, some technologies directly addressing enteric fermentation of cattle, which represents 31% of the agricultural GHG emissions have not been considered (e.g. vaccination, propionate precursors). Moreover, the share of livestock production that can apply the considered technology options is sometimes very limited and country specific (GAINS, 2013). On the other hand, almost 100% of EU crop production would potentially use the provided crop mitigation options. Under the setting of this study and based on the available information, the largest part of the required GHG reduction in the modelled mitigation policy scenarios is therefore realised by a quantitative adjustment of production (herd size, yield and cultivated hectares). The scenarios simulating the introduction of a subsidy for the implementation and use of (one or more of) the GHG mitigation technologies indicate that the subsidies lead to a higher uptake of the modeled mitigation technologies. A 60% subsidy would encourage the uptake of the anaerobic digestion plants to its maximum share for almost all MS. Notwithstanding, even with an increased uptake of the modelled mitigation technologies the overall effect on GHG mitigation is relatively limited, reaching a 4.5% reduction of GHG emissions when subsidizing the costs of the technologies by 90%.

The analysis on emission leakage reveals that policies imposing emission mitigation targets only in the EU might not necessarily lead to emission reductions on the global level. If production declines in the EU are not accompanied by equivalent decreases in EU consumption, at least part of the EU production decrease may be replaced by imports, which causes emissions outside the EU that considerably downsize the net effect on global GHG reduction. Regarding global GHG mitigation, the scenario results suggest that the modelled subsidies for mitigation technologies might achieve similar net effects as the policies with GHG reduction targets as they show only very little impact on the EU agricultural markets and hence do not entail incentives that would provoke production increases in the rest of the world and accompanying emission leakage effects.

When looking at the scenario results especially the following issues have to be kept in mind: (1) The assessed policy scenarios are all hypothetical and exploratory, and they are quite rigid and give much less flexibility than could be expected in more likely policy scenarios. A detailed EU climate change framework for 2030 will look different from the assessed policies. Furthermore, the use of mitigation technologies might be supported additionally through subsidies or through greening and cross compliance obligations. This would shift the shares of savings coming from production cuts versus mitigation technologies in the scenarios. (2) Not all technological mitigation options currently available are covered in the modelling approach of this study. Moreover, new or further improved technological and management based GHG mitigation options could be available during the projection period. This could certainly alter the scenario results, as technological innovation regarding GHG mitigation could potentially lead to emission abatement at lower costs and without (significant) reductions in agricultural activities; diminishing also any potential emission leakage effects. (3) The approach on calculating emission leakage has several limitations, as e.g. constant emission factors (over time) for non-EU regions, i.e. possible technological changes outside the EU and indirect effects of intensity changes and area re-allocations in non-EU regions are ignored. These limitations might favour an overestimation of the emission leakage effect.

In general, the results of this study should be considered as indicative and understood within the specific framework of assumptions of the study. Additional research will follow to further improve the CAPRI modelling system, especially regarding technological mitigation options and the estimation of emission leakage. Moreover, further information on possible implementation details of the EU climate change framework for 2030 is needed to further enhance the analysis.

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Annexes

Annex 1: Share of the technological mitigation option "farm anaerobic digestion" by activity in the reference and policy scenarios

	Austria										
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0	0	0	0	0	0	0	0	0	0	0
Dairy cows production activity high yield	0	0	0	0	0	0	0	0	0	0	0
Beef activities aggregated	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pig fattening	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Sows for piglet production	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

	Belgium-Luxembourg										
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.07	0.00	0.07	0.07	0.07	0.07	0.07	0.06	0.03	0.07	0.07
Dairy cows production activity high yield	0.07	0.00	0.07	0.07	0.07	0.06	0.07	0.02	0.03	0.07	0.07
Beef activities aggregated	0.04	0	0.04	0.04	0.04	0.04	0.04	0.04	0	0.004	0.02
Pig fattening	0.50	0	0	0	0	0	0	0	0.25	0.50	0.50
Sows for piglet production	0.50	0	0	0	0	0	0	0	0.25	0.50	0.50

	Denmark										
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.31	0.08	0.22	0.22	0.31	0.12	0	0	0.31	0.21	0.01
Dairy cows production activity high yield	0.31	0.08	0.27	0.27	0.31	0.18	0.02	0	0.31	0.21	0.01
Beef activities aggregated	0.21	0.05	0.19	0.19	0.18	0.19	0.19	0.19	0.11	0.11	0.08
Pig fattening	0.47	0.12	0.43	0.43	0.44	0.43	0.42	0.40	0.44	0.42	0.41
Sows for piglet production	0.47	0.12	0.43	0.43	0.43	0.42	0.41	0.38	0.44	0.42	0.41

	Finland										
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0	0	0	0	0	0	0	0	0	0	0
Dairy cows production activity high yield	0	0	0	0	0	0	0	0	0	0	0
Beef activities aggregated	0	0	0	0	0	0	0	0	0	0	0
Pig fattening	0	0	0	0	0	0	0	0	0	0	0
Sows for piglet production	0	0	0	0	0	0	0	0	0	0	0

France

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.08	0.01	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Dairy cows production activity high yield	0.08	0.01	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Beef activities aggregated	0.08	0.01	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Pig fattening	0.49	0.05	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Sows for piglet production	0.49	0.05	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49

Germany

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.13	0.04	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Dairy cows production activity high yield	0.13	0.04	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Beef activities aggregated	0.27	0.08	0.27	0.27	0.27	0.27	0.27	0.27	0.15	0.22	0.27
Pig fattening	0.35	0.10	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Sows for piglet production	0.35	0.10	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35

Greece

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.03	0	0.02	0.02	0.02	0.03	0.01	0.02	0.01	0.03	0.03
Dairy cows production activity high yield	0.03	0	0.02	0.02	0.03	0.03	0.02	0.02	0.01	0.03	0.03
Beef activities aggregated	0.05	0	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.05	0.05
Pig fattening	0.40	0	0.40	0.40	0.40	0.40	0.37	0.40	0.20	0.40	0.40
Sows for piglet production	0.40	0	0.40	0.40	0.40	0.40	0.38	0.40	0.20	0.40	0.40

Ireland

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.03	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Dairy cows production activity high yield	0.03	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Beef activities aggregated	0.04	0.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Pig fattening	0.77	0.00	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77
Sows for piglet production	0.77	0.00	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77

Italy

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.13	0	0.12	0.12	0.13	0.13	0.13	0.13	0.06	0.13	0.13
Dairy cows production activity high yield	0.13	0	0.12	0.12	0.13	0.13	0.13	0.13	0.06	0.13	0.13
Beef activities aggregated	0.24	0	0.24	0.24	0.24	0.24	0.24	0.24	0.12	0.24	0.24
Pig fattening	0.52	0	0.52	0.52	0.52	0.52	0.52	0.52	0.26	0.52	0.52
Sows for piglet production	0.52	0	0.52	0.52	0.52	0.52	0.52	0.52	0.26	0.52	0.52

	Netherlands										
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.31	0.04	0.31	0.31	0.31	0.31	0.31	0.30	0.31	0.31	0.31
Dairy cows production activity high yield	0.31	0.04	0.31	0.31	0.31	0.31	0.31	0.30	0.31	0.31	0.31
Beef activities aggregated	0.40	0.05	0.40	0.40	0.40	0.40	0.40	0.40	0.18	0.31	0.35
Pig fattening	0.57	0.07	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Sows for piglet production	0.57	0.07	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57

	Portugal										
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.03	0	0.03	0.03	0.03	0.03	0.03	0.03	0.01	0.03	0.03
Dairy cows production activity high yield	0.03	0	0.03	0.03	0.03	0.03	0.03	0.03	0.01	0.03	0.03
Beef activities aggregated	0	0	0	0	0	0	0	0	0	0	0
Pig fattening	0.31	0.27	0.27	0.27	0.31	0.31	0.28	0.28	0.15	0.31	0.31
Sows for piglet production	0.31	0.28	0.28	0.28	0.31	0.31	0.31	0.31	0.15	0.31	0.31

	Spain										
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.02	0	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02
Dairy cows production activity high yield	0.02	0	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02
Beef activities aggregated	0	0	0	0	0	0	0	0	0	0	0
Pig fattening	0.41	0	0.40	0.40	0.41	0.41	0.40	0.41	0.20	0.41	0.41
Sows for piglet production	0.41	0	0.41	0.41	0.41	0.41	0.41	0.41	0.20	0.41	0.41

	Sweden										
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.07	0.00	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Dairy cows production activity high yield	0.07	0.00	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Beef activities aggregated	0.06	0.00	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Pig fattening	0.31	0.02	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Sows for piglet production	0.31	0.02	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31

	United Kingdom										
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.19	0.04	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Dairy cows production activity high yield	0.19	0.04	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Beef activities aggregated	0.04	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03
Pig fattening	0.23	0.04	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Sows for piglet production	0.23	0.04	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23

Bulgaria

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.01	0	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01
Dairy cows production activity high yield	0.01	0	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01
Beef activities aggregated	0.02	0	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.02	0.02
Pig fattening	0.23	0	0.23	0.23	0.17	0.23	0.02	0.07	0.11	0.23	0.23
Sows for piglet production	0.23	0	0.23	0.23	0.23	0.23	0.04	0.13	0.11	0.23	0.23

Cyprus

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.09	0	0.09	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09
Dairy cows production activity high yield	0.09	0	0.09	0.09	0.09	0.09	0.09	0.09	0.05	0.09	0.09
Beef activities aggregated	0.14	0	0.12	0.12	0.06	0.11	0.08	0.13	0.00	0.01	0.06
Pig fattening	0.46	0	0.46	0.46	0.46	0.46	0.46	0.46	0.23	0.46	0.46
Sows for piglet production	0.46	0	0.46	0.46	0.46	0.46	0.46	0.46	0.23	0.46	0.46

Czech Republic

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.01	0	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01
Dairy cows production activity high yield	0.01	0	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01
Beef activities aggregated	0.03	0	0.03	0.03	0.03	0.03	0.01	0.02	0	0.00	0.01
Pig fattening	0.45	0	0.45	0.45	0.45	0.45	0.24	0.45	0.23	0.45	0.45
Sows for piglet production	0.45	0	0.45	0.45	0.45	0.45	0.30	0.45	0.23	0.45	0.45

Estonia

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.01	0	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01
Dairy cows production activity high yield	0.01	0	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01
Beef activities aggregated	0.05	0	0.05	0.05	0.05	0.05	0.02	0.05	0	0	0.02
Pig fattening	0.33	0	0.33	0.33	0.33	0.33	0.33	0.33	0.17	0.33	0.33
Sows for piglet production	0.33	0	0.33	0.33	0.33	0.33	0.33	0.33	0.17	0.33	0.33

Hungary

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.002	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00
Dairy cows production activity high yield	0.002	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00
Beef activities aggregated	0.02	0	0.02	0.02	0.02	0.02	0.00	0.02	0.01	0.02	0.02
Pig fattening	0.34	0	0.21	0.21	0.31	0.34	0	0.02	0.17	0.34	0.34
Sows for piglet production	0.34	0	0.30	0.30	0.34	0.34	0	0.06	0.17	0.34	0.34

Latvia

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.004	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dairy cows production activity high yield	0.004	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beef activities aggregated	0.003	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pig fattening	0.22	0	0.22	0.22	0.22	0.22	0.17	0.22	0.11	0.22	0.22
Sows for piglet production	0.22	0	0.22	0.22	0.22	0.22	0.22	0.22	0.11	0.22	0.22

Lithuania

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.04	0	0.04	0.04	0.04	0.04	0.04	0.04	0.02	0.04	0.04
Dairy cows production activity high yield	0.04	0	0.04	0.04	0.04	0.04	0.04	0.04	0.02	0.04	0.04
Beef activities aggregated	0.05	0	0.05	0.05	0.05	0.05	0.00	0.03	0	0.01	0.02
Pig fattening	0.32	0	0.32	0.32	0.32	0.32	0.13	0.32	0.16	0.32	0.32
Sows for piglet production	0.32	0	0.32	0.32	0.32	0.32	0.20	0.32	0.16	0.32	0.32

Malta

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0	0	0	0	0	0	0	0	0	0	0
Dairy cows production activity high yield	0	0	0	0	0	0	0	0	0	0	0
Beef activities aggregated	0	0	0	0	0	0	0	0	0	0	0
Pig fattening	0.64	0	0.64	0.64	0.34	0.59	0.34	0.64	0.32	0.64	0.64
Sows for piglet production	0.64	0	0.64	0.64	0.53	0.64	0.53	0.64	0.32	0.64	0.64

Poland

	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.03	0	0.03	0.03	0.03	0.03	0.01	0.02	0.01	0.03	0.03
Dairy cows production activity high yield	0.03	0	0.03	0.03	0.03	0.03	0.01	0.02	0.01	0.03	0.03
Beef activities aggregated	0.05	0	0.05	0.05	0.05	0.05	0.02	0.04	0	0.01	0.02
Pig fattening	0.16	0	0.13	0.13	0.16	0.16	0.01	0.05	0.08	0.16	0.16
Sows for piglet production	0.16	0	0.14	0.14	0.16	0.16	0.02	0.07	0.08	0.16	0.16

Romania

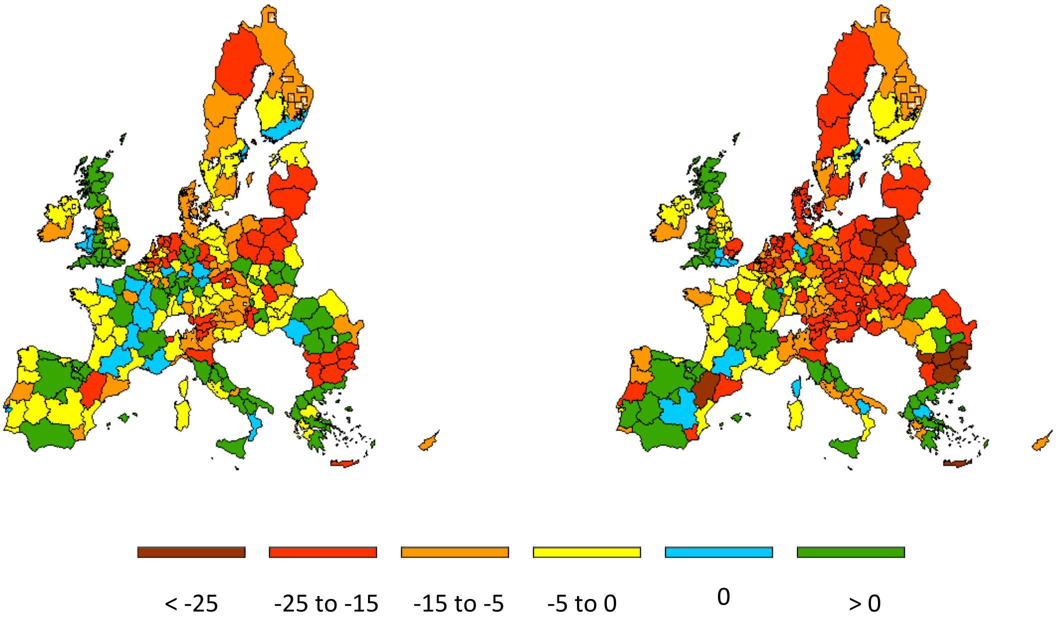
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.01	0	0.00	0.00	0.01	0.01	0	0	0.01	0.01	0.01
Dairy cows production activity high yield	0.01	0	0.00	0.00	0.01	0.01	0	0	0.01	0.01	0.01
Beef activities aggregated	0.04	0	0.03	0.03	0.04	0.04	0	0.00	0.02	0.04	0.04
Pig fattening	0.45	0	0.19	0.19	0.45	0.45	0	0	0.23	0.45	0.45
Sows for piglet production	0.45	0	0.25	0.25	0.45	0.45	0	0	0.23	0.45	0.45

	Slovak Republic									
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.06	0	0.03	0.03	0.03	0.03	0.00	0.03	0.02	0.03	0.03
Dairy cows production activity high yield	0.06	0	0.03	0.03	0.03	0.03	0.01	0.03	0.02	0.03	0.03
Beef activities aggregated	0.10	0	0.05	0.05	0.05	0.05	0.01	0.05	0.03	0.05	0.05
Pig fattening	0.36	0	0.32	0.32	0.32	0.32	0.00	0.14	0.16	0.32	0.32
Sows for piglet production	0.36	0	0.32	0.32	0.32	0.32	0.01	0.18	0.16	0.32	0.32

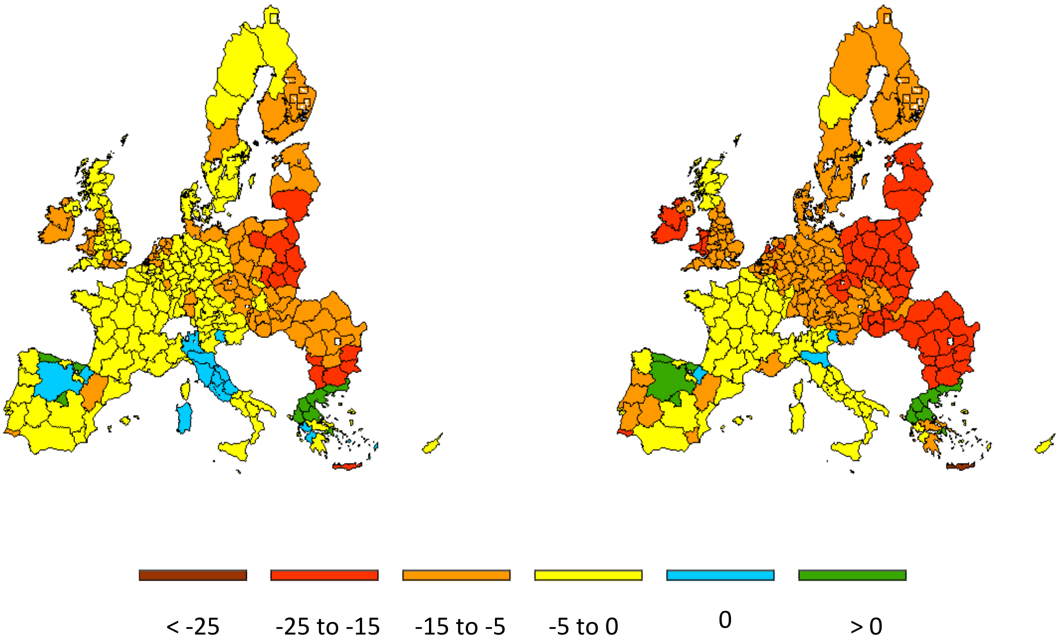
	Slovenia										
	max	REF	HOM 19	HOM 28	HOM 19ET	HOM 28ET	HET 19	HET 28	SUBS 30	SUBS 60	SUBS 90
Dairy cows production activity low yield	0.06	0	0.06	0.06	0.06	0.06	0.05	0.06	0.03	0.06	0.06
Dairy cows production activity high yield	0.06	0	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.06	0.06
Beef activities aggregated	0.10	0	0.10	0.10	0.10	0.10	0.10	0.10	0.05	0.10	0.10
Pig fattening	0.36	0	0.30	0.30	0.22	0.36	0.01	0.20	0.18	0.36	0.36
Sows for piglet production	0.36	0	0.36	0.36	0.35	0.36	0.04	0.31	0.18	0.36	0.36

Annex 2: Regional production changes in the mitigation policy scenarios (%-changes compared to REF)

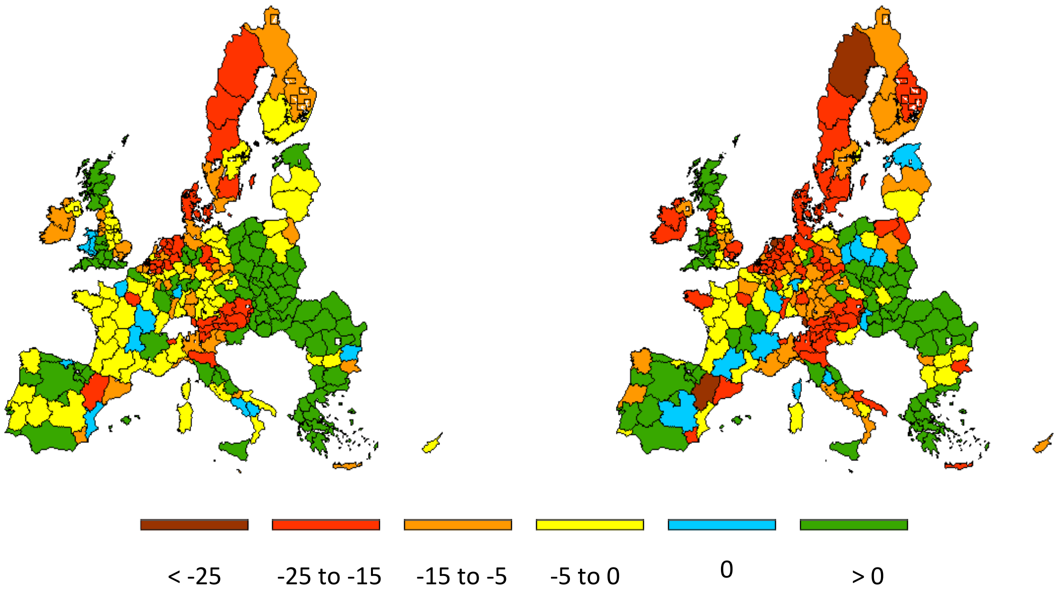
Annex 2.1: Changes in milk production (%) in HOM19 and HOM28, by NUTS2 region



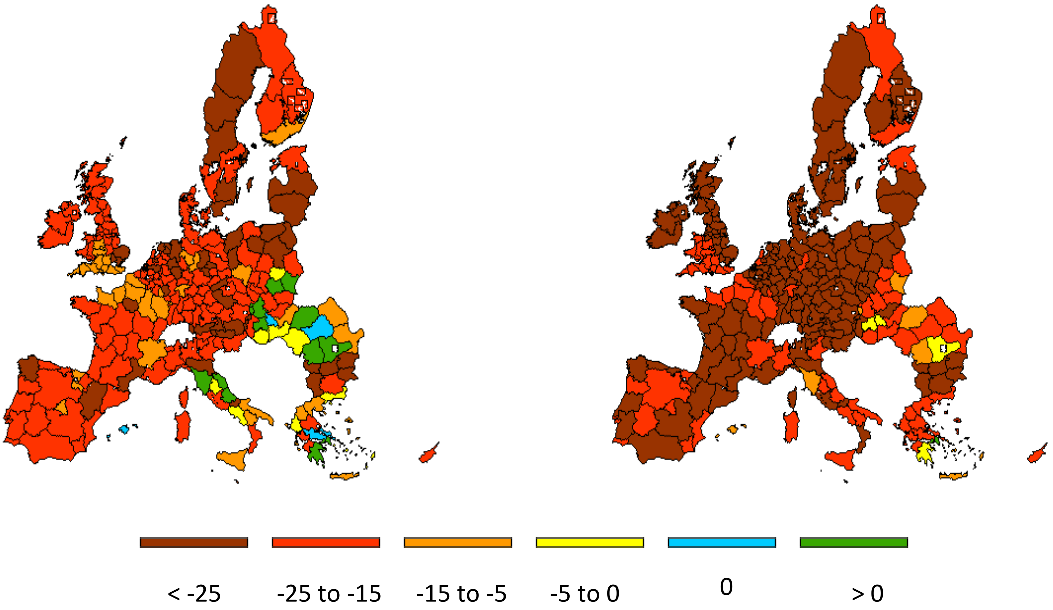
Annex 2.2: Changes in milk production (%) in HOM19ET and HOM28ET, by NUTS2 region



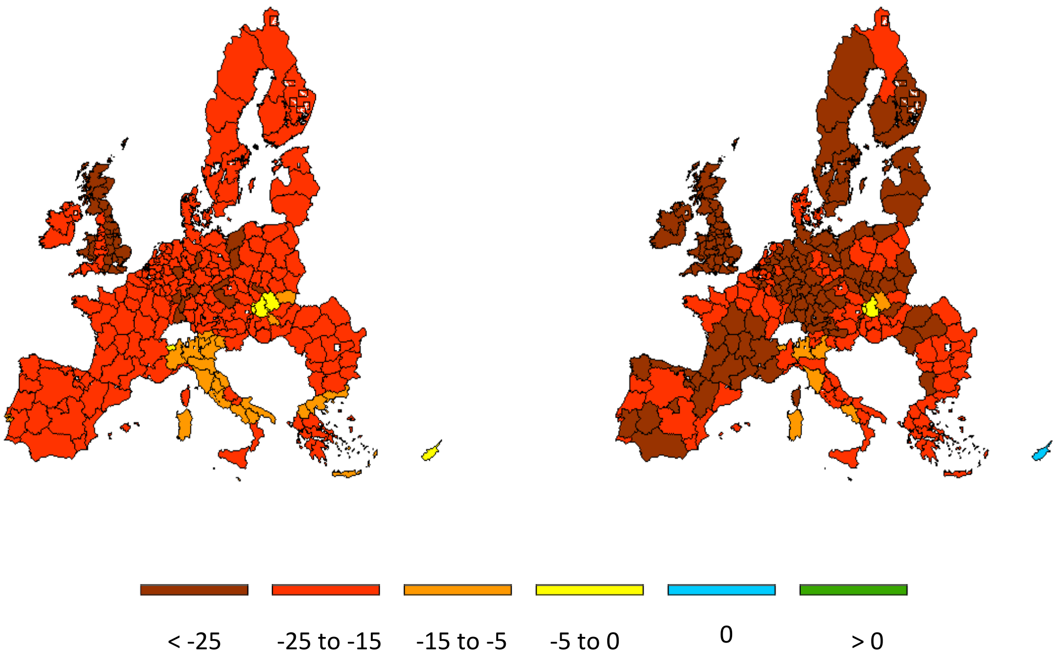
Annex 2.3: Changes in milk production (%) in HET19 and HET28, by NUTS2 region



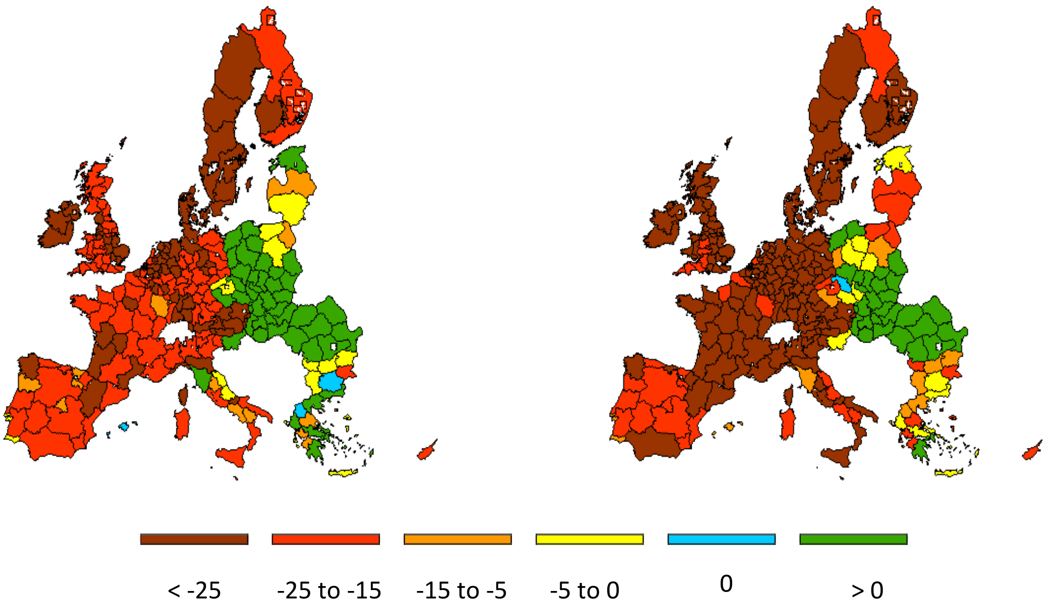
Annex 2.4: Changes in beef production (%) in HOM19 and HOM28, by NUTS2 region



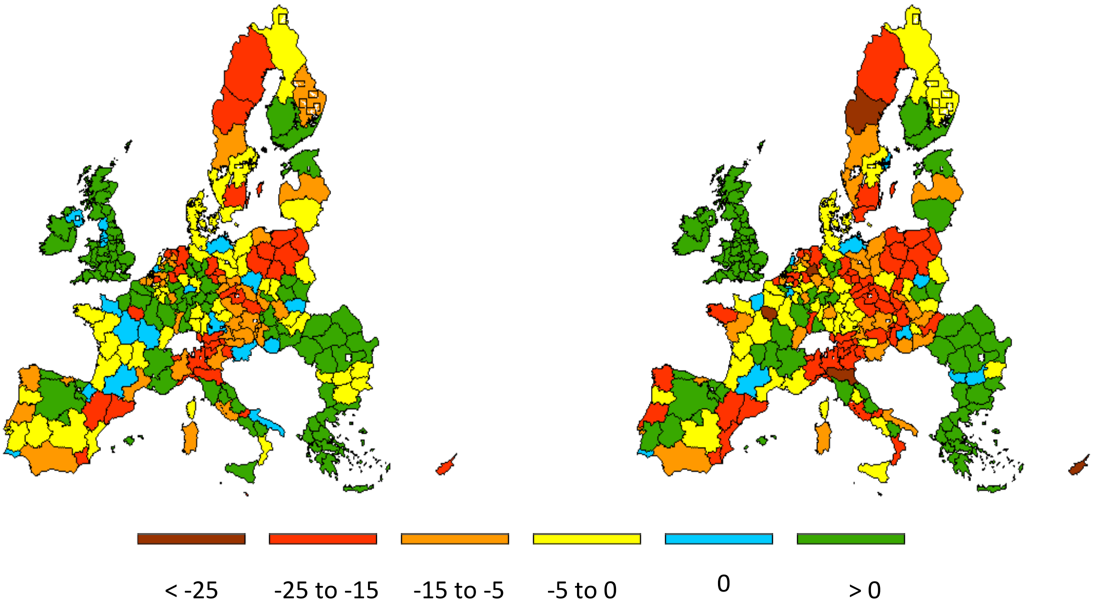
Annex 2.5 Changes in beef production (%) in HOM19ET and HOM28ET, by NUTS2 region



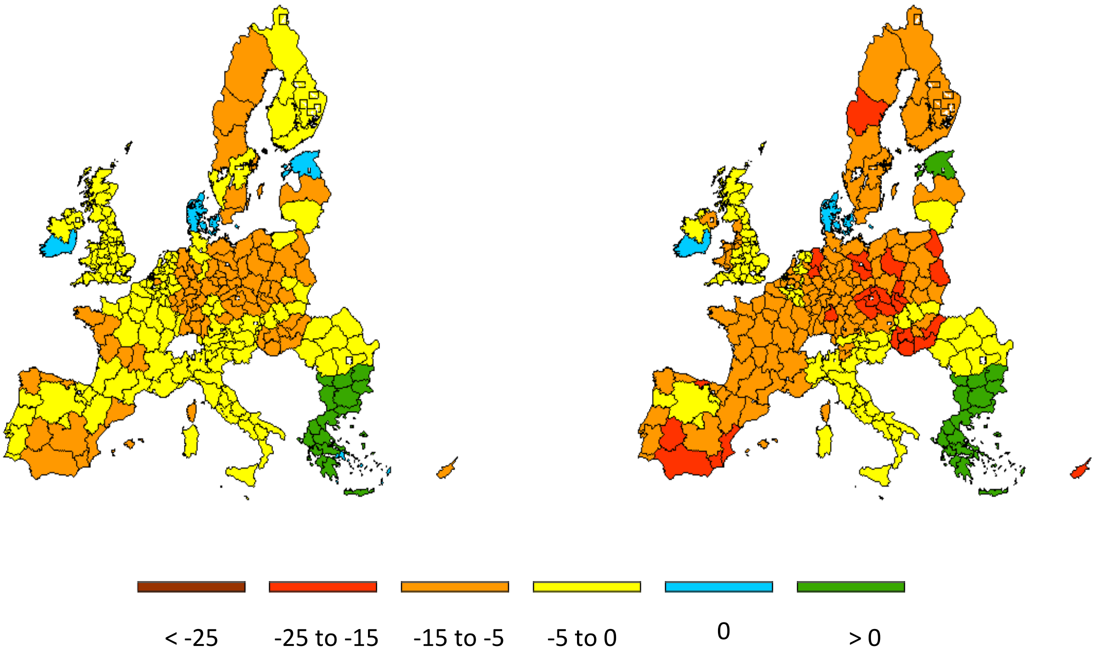
Annex 2.6 Changes in beef production (%) in respect to HET19 and HET28, by NUTS2 region



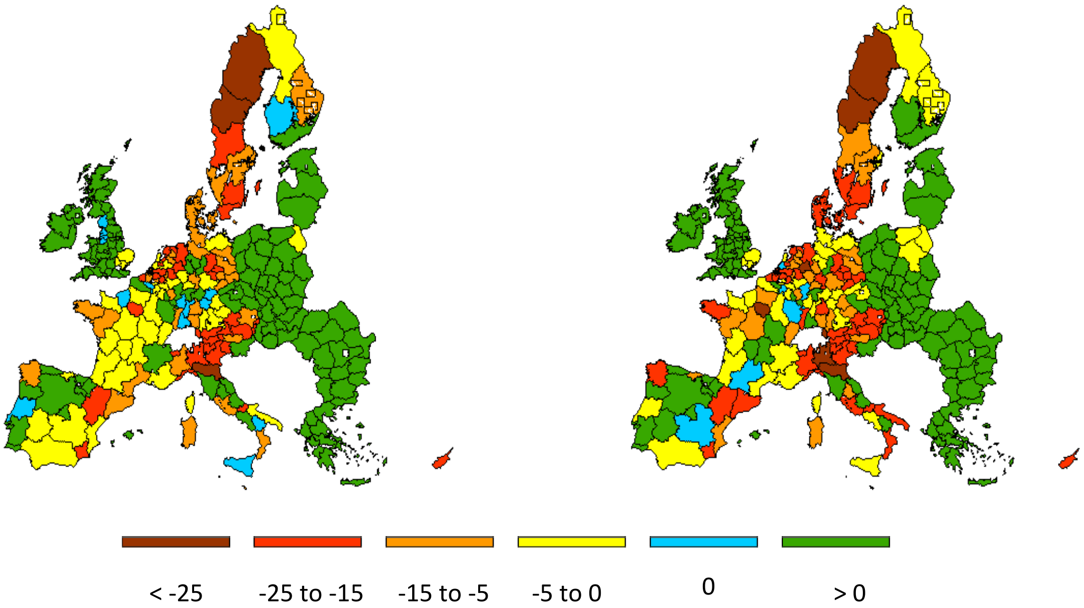
Annex 2.7 Changes in pork production (%) in HOM19 and HOM28, by NUTS2 region



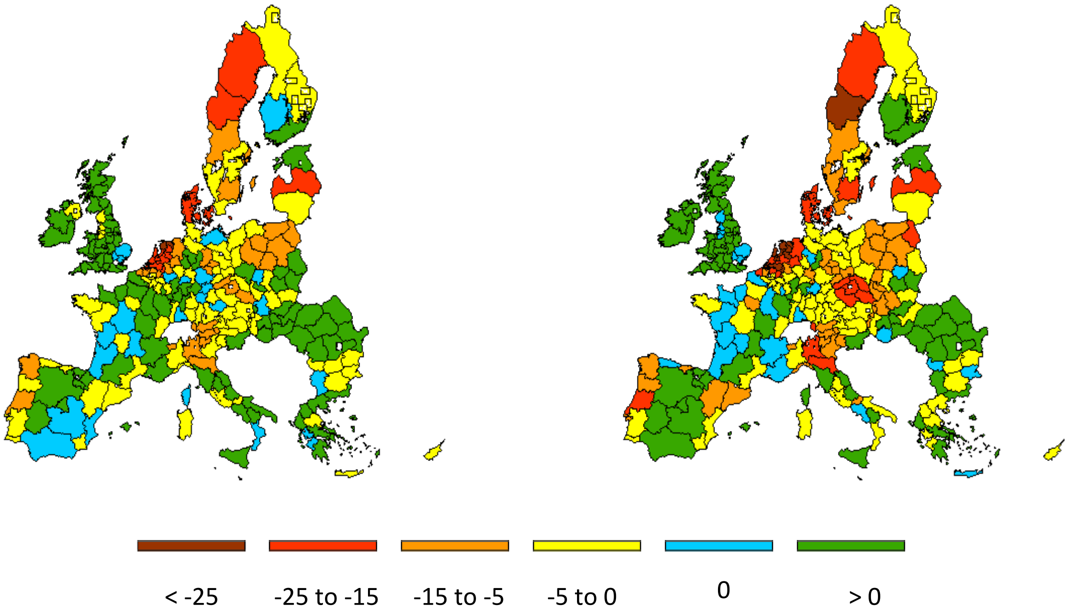
Annex 2.8 Changes in pork production (%) in HOM19ET and HOM28ET, by NUTS2 region



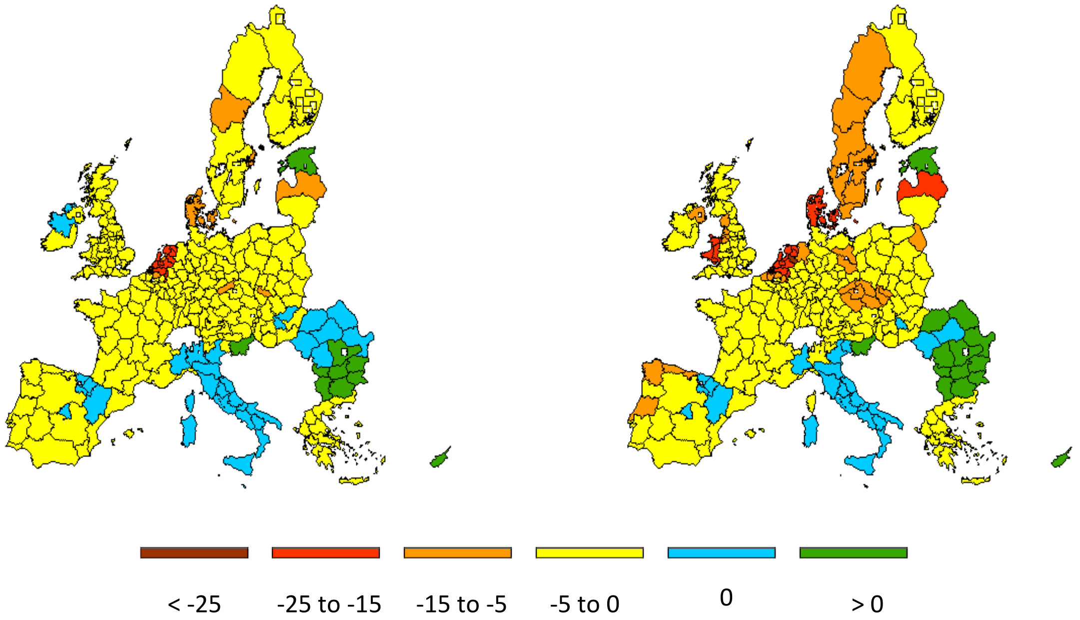
Annex 2.9 Changes in pork production (%) in HET19 and HET28, by NUTS2 region



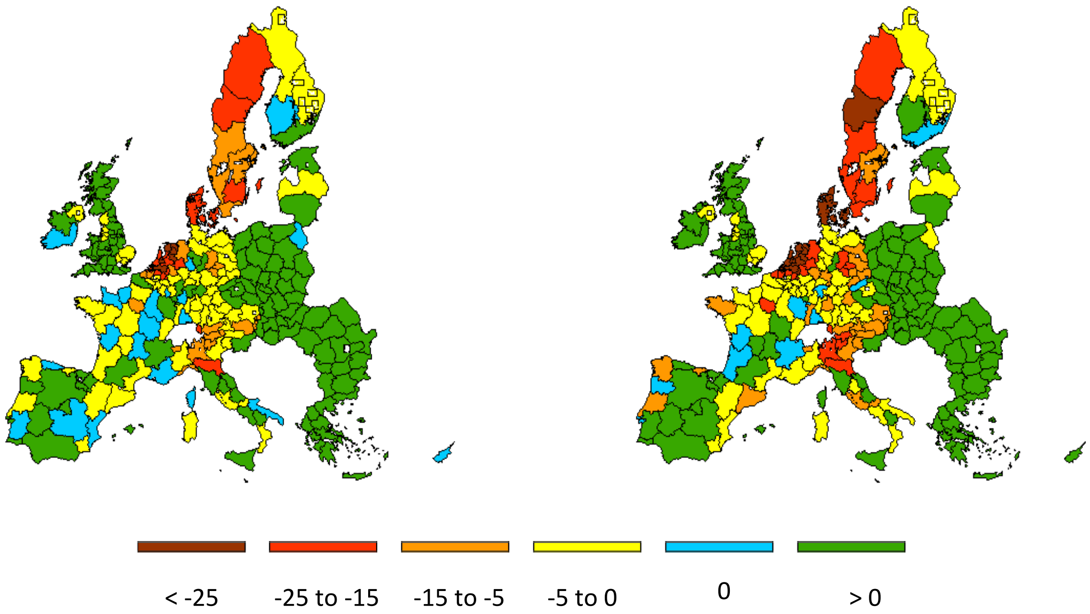
Annex 2.10 Changes in poultry meat production (%) in HOM19 and HOM28, by NUTS2 region



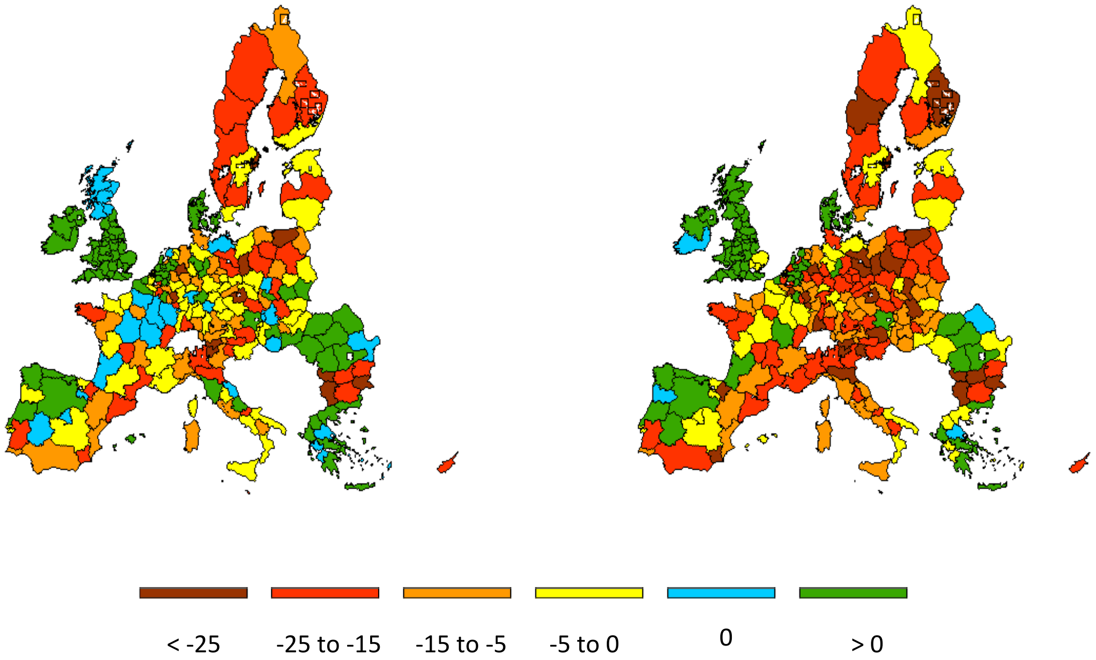
Annex 2.11 Changes in poultry meat production (%) in HOM19ET and HOM28ET, by NUTS2 region



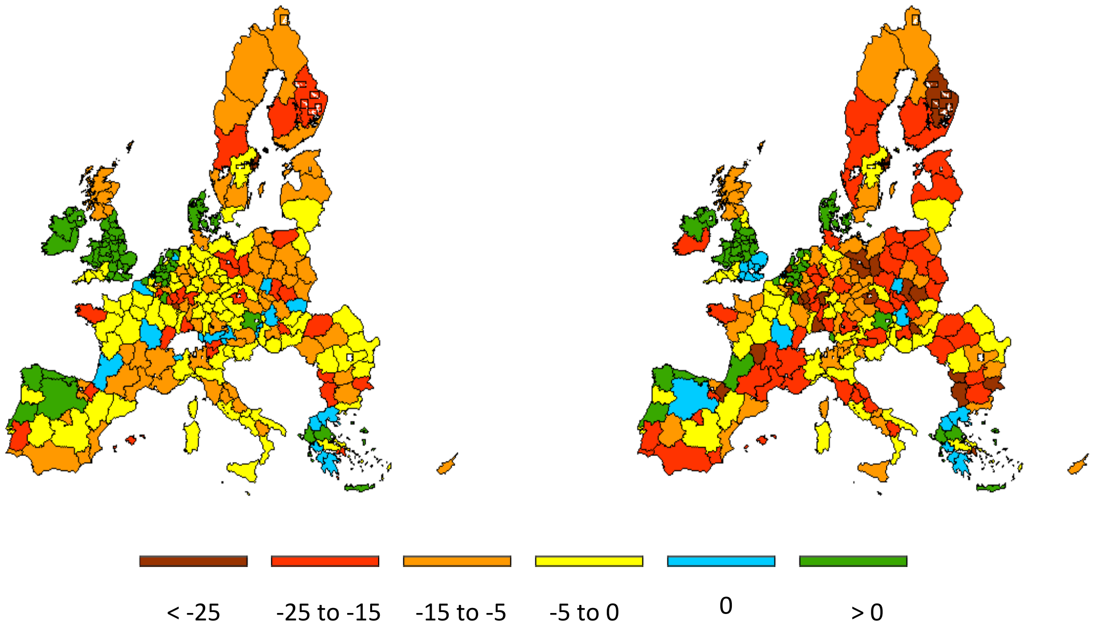
Annex 2.12 Changes in poultry meat production (%) in HET19 and HET28, by NUTS2 region



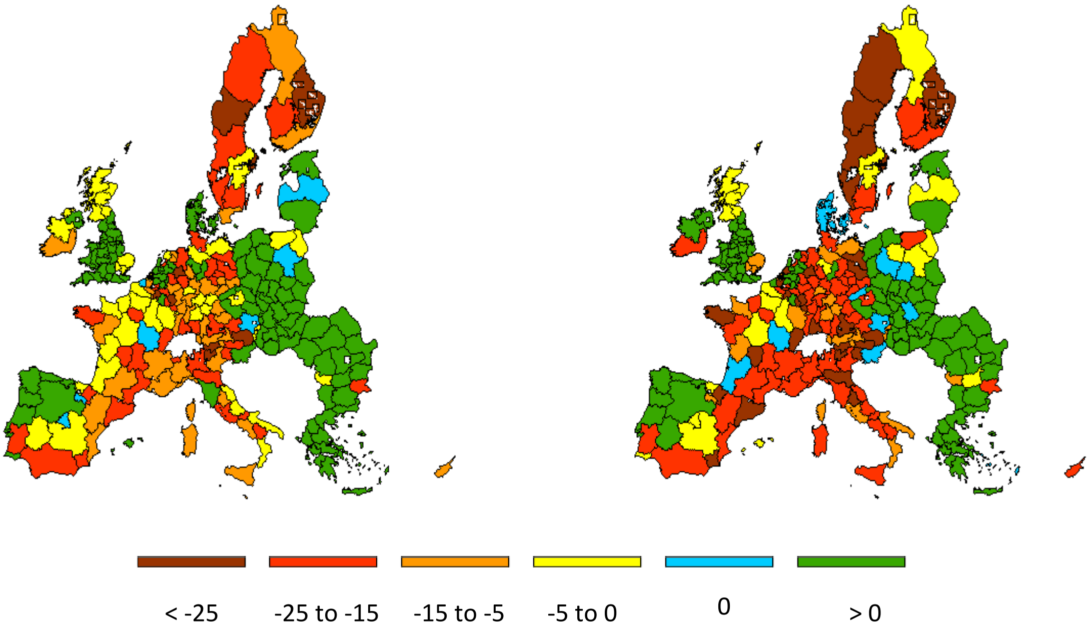
Annex 2.13 Changes in cereal production (%) in HOM19 and HOM28, by NUTS2 region



Annex 2.14 Changes in cereal production (%) in HOM19ET and HOM28ET, by NUTS2 region



Annex 2.15 Changes in cereal production (%) according to HET19 and HET28, by NUTS2 region



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