EUROPEAN COMMISSION

JOINT RESEARCH CENTRE

Institute for Environment and Sustainability (IES)
Institute for the Protection and Security of the Citizen (IPSC)
Institute for Prospective Technological Studies (IPTS)

Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS)

- Executive summary -

Administrative Arrangements AGRI-2008-0245 and AGRI-2009-0296

Franz Marc: Die Gelbe Kuh (1911)*

1

---

* Source: Wikimedia Commons (http://commons.wikimedia.org/wiki/File:Franz_Mark-The_Yellow_Cow-1911.jpg)

Adrian Leip[1], Franz Weiss[1], Tom Wassenaar[2,4], Ignacio Perez[3,5], Thomas Fellmann[3], Philippe Loudjani[2], Francesco Tubiello[2], David Grandgirard[2,6], Suvi Monni[1,7], Katarzyna Biala[1,8] (2010): Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS) –final report. European Commission, Joint Research Centre.

[1] *European Commission - Joint Research Centre - Institute for Environment and Sustainability*
[2] *European Commission - Joint Research Centre -Institute for the Protection and Security of the Citizen*
[3] *European Commission - Joint Research Centre - Institute for Prospective Technological Studies*
[4] *Now at cirad, France*
[5] *Now at OECD, France*
[6] *Now at Institut Polytechnique LaSalle Beauvais, France*
[7] *Now at benviroc, Finland*
[8] *Now at EEA, Denmark*

Date: 30.11.2010
Internal reference: Leip+2010.GGELS-report.doc

Acknowledgement:

We are grateful for a thorough review and constructive comments from the members of the advisory board and of the steering group of this project: Christel Cederberg (Swedish Institute for Food and Biotechnology, Sweden), Pierre Gerber (UN-FAO, Italy), Stanislav Jas (Copa-Cogeca, Organization of the European Farmers and European Agri-Cooperatives, Belgium), Ceris Jones (National Farmers Union, UK), Liam Kinsella (Department of Agriculture, Fisheries and Food, Irish Government, Ireland), Søren O. Petersen (Aarhus University, Dept. of Agroecology and Environment, Denmark), Frank O'Mara (Teagasc, Agriculture and Food Development Authority, Ireland), Henk Westhoek (Netherlands Environmental Assessment Agency, The Netherlands), Maria Fuentes (DG-AGRI.H04), Joao Silva (DG-AGRI.H04), Zoltan Rakonczay (DG ENV.$B_0$1), Luisa Samarelli (DG ENV.$B_0$1), Myriam Driessen (DG AGRI.H04), Jana Polakova (DG ENV.$B_0$1)

Contact:

Adrian Leip, Joint Research Centre, Institute for Environment and Sustainability, Climate Change Unit (TP 290), I - 21020 Ispra (VA) – Italy.
e-mail: **adrian.leip@jrc.ec.europa.eu**

Contents

List of tables

List of figures

EXECUTIVE SUMMARY

Introduction

The FAO report "*Livestock long shadow: environmental issues and options*" (2006) claims that livestock production is a major contributor to the world's environmental problems, contributing about 18% to global anthropogenic greenhouse gas (GHG) emissions, although highly variable across the world. FAO (2010) asserts that the global dairy sector contributes with 3.0%-5.1% to total anthropogenic GHG emissions. The FAO studies are based on a food-chain approach, bringing into light also contributions normally 'hidden' in other sectors when the internationally agreed methodology of GHG emissions accounting within the United Nations Framework Convention on Climate Change (UNFCCC) is used.

The objective of the GGELS project was to provide an estimate of the net emissions of GHGs and ammonia (NH_3) from livestock sector in the EU-27 according to animal species, animal products and livestock systems following a food chain approach.

The system boundaries of this project are schematically shown in Figure ES1. Considered are all on-farm emissions related to livestock rearing and the production of feed, as well as emissions caused by providing input of mineral fertilizers, pesticides, energy, and land for the production of feed. While the focus is on emissions from livestock production in Europe, crop production is assessed as far as used to feed the animals, independently where the crop was produced. Emissions caused by feed transport to the European farm as well as emissions from processing are also included. Emissions from livestock production are estimated for EU-27 Member States with a spatial detail of NUTS 2 regions.

The emission sources considered include (i) on-farm livestock rearing including enteric fermentation, manure deposition by grazing animals, manure management and application of manure to agricultural land; (ii) fodder and feed production including application of mineral fertiliser, the cultivation of organic soils, crop residues and related upstream industrial processes (fertilizer production); (iii) on-farm energy consumption related to livestock and feed production and energy consumption for the transport and processing of feed; (iv) land use changes induced by the production of feed (excluding grassland and grazing); and (v) emissions (or removals) from land use through changes in carbon sequestration rates related to feed production (including grassland and grazing).

Emissions are calculated for all biogenic greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). In addition, emissions of NH_3 and NO_x are estimated because of their role as precursors of the greenhouse gas N_2O and their role for air pollution and related problems. Greenhouse gas emissions are expressed in kg of emitted gas (N_2O, CH_4, CO_2), while emissions of the other reactive nitrogen gases are expressed in kg of emitted nitrogen (NH_3-N, NO_x-N). A complete list of emission sources considered and the associated gaseous emissions is given in Table ES1. Table ES1 indicates also whether the emissions are caused directly by livestock rearing activities or cropping activities for the production of feed.

The study covers the main food productive animal species: (i) beef cattle, (ii) dairy cattle, (iii) small ruminants (sheep and goats), (iv) pigs, and (v) poultry.

Animal products considered are meat (beef, pork, poultry, and meat from sheep and goats), milk (cow milk and milk from sheep and goats), and eggs. Allocation of emissions between multiple products throughout the supply chain is done on the basis of the nitrogen content of the products with the exception of the allocation of CH_4 emissions from enteric fermentation and manure management of dairy cattle, which is allocated to milk and beef on the basis of the energy requirement for lactation and pregnancy, respectively.

As functional unit for meat we use the carcass of the animal. The functional unit of milk is given at a fat content of 4% for cow milk, and 7% for sheep and goat milk, and for eggs we consider the whole egg including the shell.

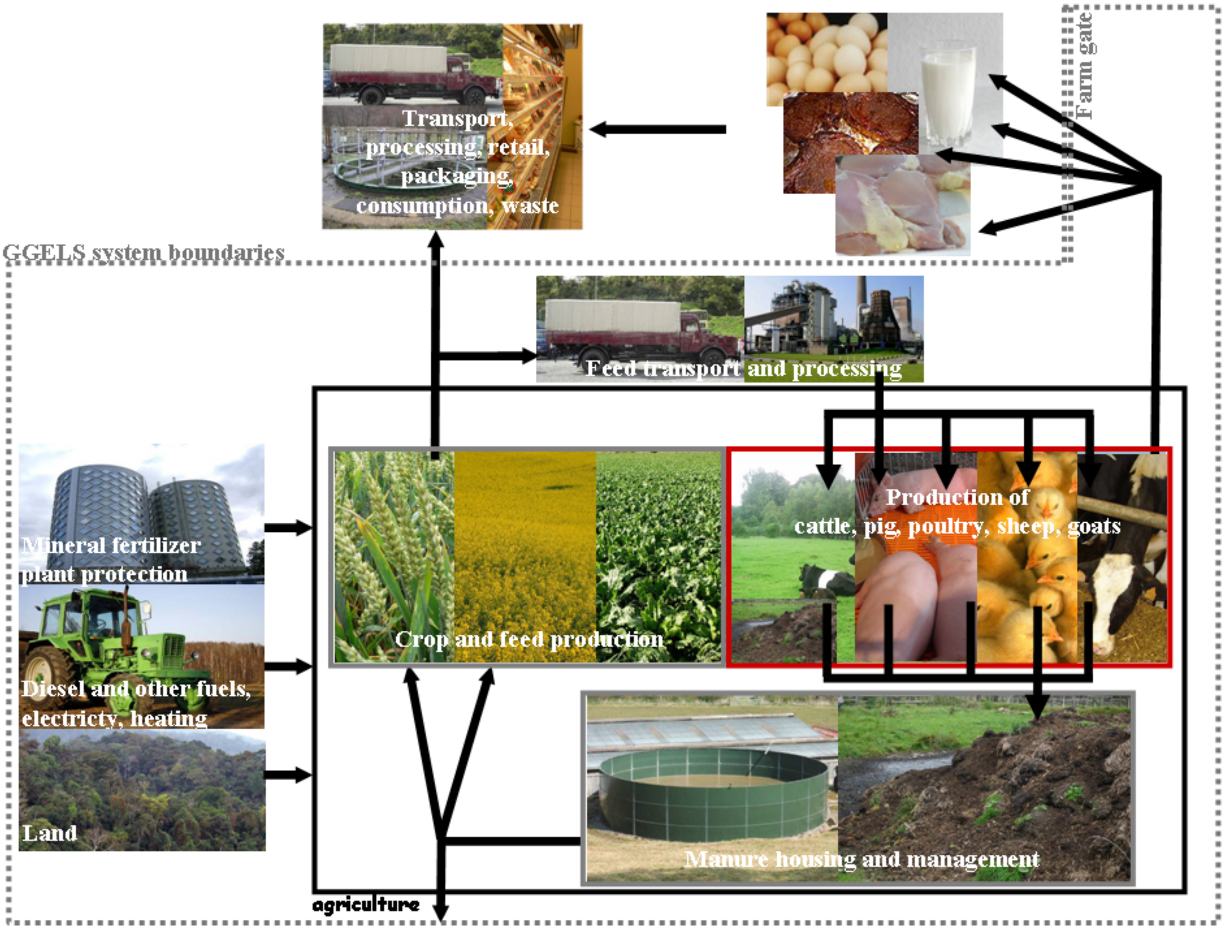

Figure ES1. System boundaries for the GGELS project.

The present report provides an in-depth analysis of the livestock sector of the European Union, starting from a general overview of this sector, developing a new livestock typology and quantifying its GHG and NH_3 emissions on the basis of the CAPRI modelling system, both *ex-post* for the year

2004 and *ex-ante* according to the latest CAPRI projections for the year 2020. The CAPRI model has been thoroughly updated for GGELS to reflect the latest scientific findings and agreed methodologies by the IPCC and extended in order to allow a cradle-to-farm-gate calculation. The report is complemented by an overview of the impact of the EU livestock sector on biodiversity, an analysis of the reduction potential with technological measures and an assessment of selected policy mitigation scenarios.

Despite the ambitious scope of the project and the large amount of information and data compiled, it is important to keep the limitations of this study in mind:

- GGELS is strictly restricted to the assessment of animal production systems in Europe, not considering the livestock sector from a consumer's perspective. We have nevertheless included a brief assessment of the GHG emissions of the most important animal products imported from non-European countries, using, however, a different methodology than the one applied throughout the rest of the study.

- GGELS can not provide a realistic quantification of emission abatement potentials, be it through technological reduction measures or policy mitigation options. We provide nevertheless an assessment of the technological potential of selected reduction measures and explore a few policy options.

- Environmental effects other than GHG and NH_3 emissions and biodiversity under present conditions have not been considered.

- There is little known about the uncertainty of the estimates; we have included a comparison with official estimates to the UNFCCC, but a thorough uncertainty assessment was not part of the study.

Overview of the EU livestock sector

Throughout the EU the livestock sector is a major player of the agricultural economy and its land use. The relative importance of different subsectors varies enormously among MS, influenced at the same time by cultural values and bio-physical conditions (pork in Spain and beef in Ireland), while economic conditions also interfere (small ruminants often playing a larger role in more subsistence production oriented economies). Within each sub sector a range of production systems occurs. Even though a trend has been seen in the last decades to increasing intensification and larger farm units in all Member States of the European Union, diversity of farming systems remains large. This is explained by the biophysical conditions in different regions of Europe, pushing farmers in countries with short vegetation period or insufficient rain to more intensive production (high input/output systems) while wet lowlands in mild climate or mountainous regions extensify animal raising (low input/output systems). The situation was particularly dynamic in the eight Central Eastern European countries accessing the EU at the 2004 enlargement. On the average, productivity in this eight countries is well below EU15 average and a continuing increase is expected. Nevertheless, the bulk of livestock produces are supplied by very large entities, for example in 2004, 39% of milk in EU15 was produced by 11% of the dairy farms with milk quota over 400,000 kg. IPPC pig farms represent only 0.3% of EU fattening pig farms, but they contain 16% of the population. IPPC poultry farms

(>40.000 head) represent only 0.1% of laying hen farms, but contain 59% of the laying hen population.

Typology of Livestock Production System in Europe

Livestock production systems (LPS) in Europe were characterized for the six main sectors, i. e., dairy cattle for milk production (BOMILK), meat production from bovine livestock (BOMEAT), meat production from poultry (POUFAT), egg production (LAHENS), meat and milk production from sheep and goats (SHGOAT) and pig production (meat and raising – PORCIN). Description of the LPS in Europe was done at the regional level using 8 groups of descriptors (animal assemblage, climate, intensity level, productivity level, cropping system, manure production, feeding strategy and environmental impact). For the quantification of these description the CAPRI database was used, extended by data from JRC Agri4cast action (climate), INRAtion© (feeding strategy) and Eurostat (farm types).

Regional zoning was done on the basis of a purely statistical approach of clustering the regions with respect to each of these groups of descriptors (dimensions). Clustering was done for each LPS considered or for all sectors together in the case of the animal assemblages-dimension. Raw data were directly extracted from CAPRI or other databases used and expressed as absolute (n) and relative (%) quantities. Results are presented as maps. As an example, results for the BOMILK sector are presented. Results showed that BOMILK revenues were generally correlated with the level of intensity, suggesting a positive relationship between the production and the magnitude of the investment spent for feedstuffs and veterinary products. BOMILK systems based on fodder production have to a lesser extent recourse to market for feedstuffs supplies. The herd size can be largely increased when a higher part of the total UAA is cultivated with fodder maize. Clusters were defined by five components: production system (subsidiary/primary), intensity level (intensive/extensive), housing system (indoor/mixed/outdoor), market dependence (very dependent/dependent/ independent), and main feedstuff used (marketed/pasture and maize/pasture and grazing/hay). For BOMILK, seven clusters are identified: climate constrained, extensive grassland, free-ranging subsistence, grazing complement, intensive grass+maize, intensive maize and Mediterranean intensive. For BOMEAT, the identified clusters were complement to ovine, complement to porcine, intensive grass+maize, intensive maize, subsidiary Mediterranean, subsidiary nordic, no BOMEAT.

A questionnaire on manure management systems to improve the poor data situation in Europe sent out to over 400 regional experts across Europe, unfortunately, had only little return. Thus, in contrast to the expectations, the LPS typology could not be improved with detailed information on manure management systems. Nevertheless, some general observations could be made for the BOMILK sector on the basis of good data obtained for some regions in six European countries.

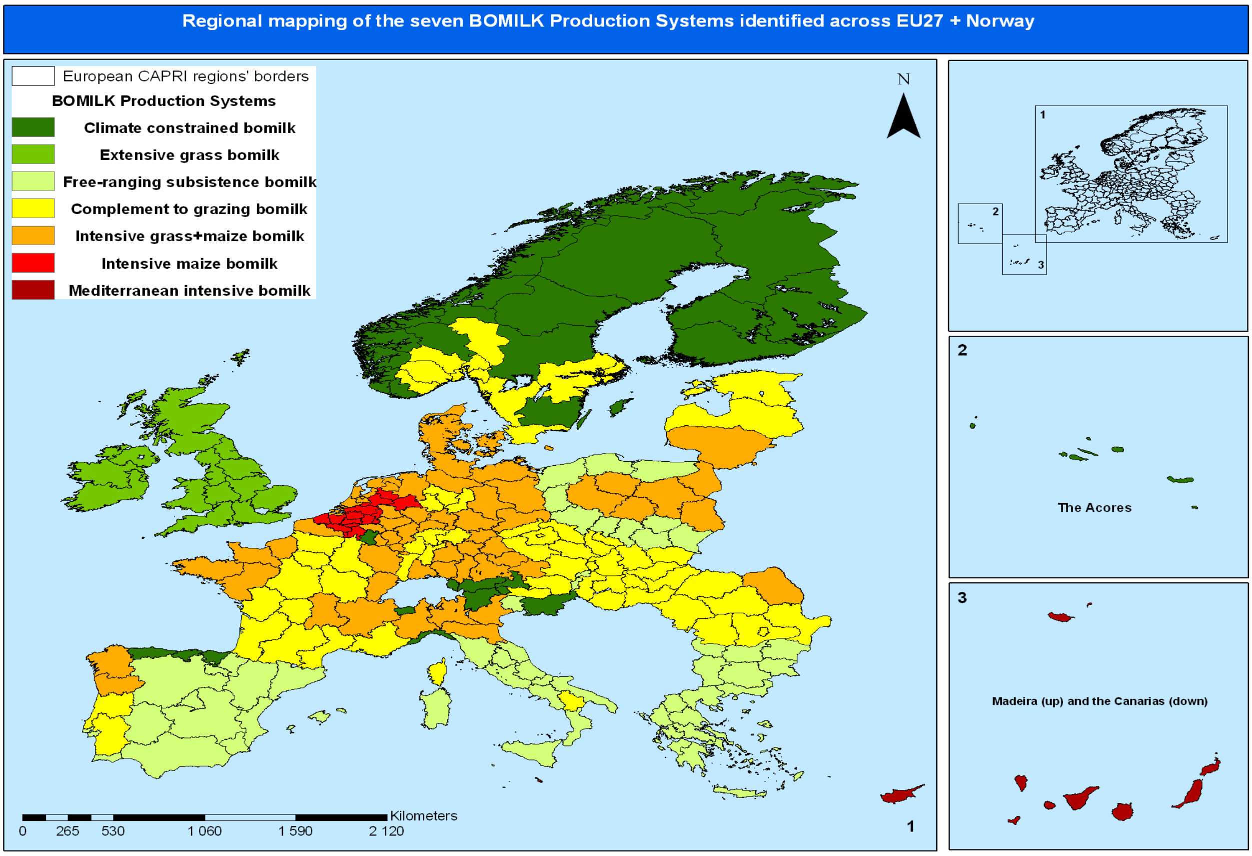

Figure ES2: Diversity of the BOMILK Production Systems in EU-27 + Norway

Methodology for Quantification of greenhouse gas and ammonia emissions from the livestock sector the

The quantification of greenhouse gas and ammonia emissions from the EU livestock sector is carried out with the CAPRI model for the base year 2004. On the one hand, for all those emissions which are considered in the agricultural sector of the National Inventories, results are available on the level of agricultural activities, generally indicated by crop area or livestock heads, in order to facilitate the comparison with official emission data. Activity based emissions generally consider only emissions which are directly created by the respective activity, like i.e. the fattening of young bulls, in the respective country or region. On the other hand a life cycle approach (LCA) was carried out which gives a more comprehensive idea of all emissions caused by the EU livestock sector (including emissions from inputs). In this life cycle assessment results are expressed on the level of animal products. The functional unit, in our case is one kilogram of carcass meat, milk (at 4% / 7% fat content for cow and sheep/goat milk, respectively), or eggs.

The CAPRI model had already a detailed GHG module implemented, however, requiring the implementation of new calculation modules such as (i) the calculation of product-based emissions on the basis of the Life Cycle approach; (ii) emissions from land use change; (iii) emissions and emission savings from carbon sequestration of grassland and cropland; (iv) N_2O and CO_2 emissions from the cultivation of organic soils; and (v) emissions of feed transport. Further improvements concern the update of the methodology according to the new IPCC guidelines (IPCC, 2006). Other parts that have been improved include the module for estimating CH_4 emissions from enteric fermentation (endogenous calculation of feed digestibility), CH_4 emissions from manure management (detailed representation of climate zones), update and correction of MITERRA N_2O loss factors, and ensuring consistent use of parameters throughout the model.

Table ES1. Emission sources considered in the GGELS project

Emission source	**Livestock rearing**	**Feed production**	**Gases**
• Enteric fermentation	X		CH_4
• Livestock excretions			
o Manure management (housing and storage)	X		NH_3, N_2O, CH_4, NO_x
o Depositions by grazing animals	X		NH_3, N_2O, NO_x
o Manure application to agricultural soils	X		NH_3, N_2O, NO_x
o Indirect emissions, indirect emissions following N-deposition of volatilized NH_3/NO_x from agricultural soils and leaching/run-off of nitrate	X		N_2O
• Use of fertilizers for production of crops dedicated to animal feeding crops (directly or as blends or feed concentrates, including imported feed)			
o Manufacturing of fertilizers		X	CO_2, N_2O
o Use of fertilizers, direct emissions from agricultural soils and indirect emissions		X	NH_3, N_2O
o Use of fertilizers, indirect emissions following N-deposition of volatilized NH_3/NO_x from agricultural soils and leaching/run-off of nitrate		X	N_2O
• Cultivation of organic soils		X	CO_2, N_2O
• Emissions from crop residues (including leguminous feed crops)		X	N_2O
• Feed transport (including imported feed)		X	$CO_{2\text{-eq}}$
• On-farm energy use (diesel fuel and other fuel electricity, indirect energy use by machinery and buildings)		X	$CO_{2\text{-eq}}$
• Pesticide use		X	
• Feed processing and feed transport		X	CO_2
• Emissions (or removals) of land use changes induced by livestock activities (feed production or grazing)			
o carbon stock changes in above and below ground biomasss and dead organic matter		X	CO_2,
o soil carbon stock change		X	CO_2,
o biomass burning		X	CH_4 and N_2O
• Emissions or removals from pastures, grassland and cropland	X	X	CO_2

Product-based LCA emission estimates are obtained in three steps: first, those emissions which can be related to an agricultural activity are calculated per hectare of crop cultivated or per head of livestock raised. Second, those emissions which are more related to products are directly quantified on a per-product basis (CO_2 emissions from feed transport and GHG emissions from land use change). Third, activity-based emissions are converted to product-based emissions using defined allocation rules and all product-based emission estimates are carried through the supply chain and finally allocated to the final functional units, again following defined allocation rules.

The quantification of methane emissions from enteric fermentation and manure management follows the IPCC 2006 guidelines, a Tier 2 approach for cattle activities and a Tier 1 approach for swine, poultry, sheep and goats. Feed digestibility is calculated on the basis of the feed ration estimated in CAPRI and literature factors. Nitrogen emissions are calculated according to a mass flow approach developed by the MITERRA-EUROPE project using data of the RAINS database. It considers emissions from grazing animals, manure management, manure and mineral fertilizer application, nitrogen delivery of crop residues and N-fixing crops, indirect N_2O emissions from volatilized NH_3 and NO_X, and from leaching and runoff. A distinction is made between liquid and solid manure management systems. Generally, in a first step default emission factors are applied, then in a second step emission reductions are considered according to supposed usage of abatement technologies. CO_2 and N_2O emissions from the cultivation of organic soils are calculated following IPCC 2006 guidelines, using data from Leip et al. (2008). The quantification of emissions from on-farm energy usage follows an approach developed by Kraenzlein (2008), which considers direct emissions from diesel fuel, heating gas and electricity usage, indirect emissions from machinery and buildings, and, finally, emissions from pesticide usage, generally accounted in $CO_{2\text{-eq}}$. It follows an LCA-approach in itself, providing emission factors to be used for crop- and animal production activities. Furthermore, N_2O and CO_2 emissions from the manufacturing of mineral fertilizers and CO_2 emissions from feed transport are included in the analysis, using a simplified approach developed at the University of Bonn, the main developer of the CAPRI model, and at the JRC.

CO_2 fluxes from carbon sequestration of grassland and cropland are estimated on the basis of data derived from Soussana et al. (2007; 2009). The approach relies on the finding that carbon sequestration in natural grasslands has no saturation effect, but is continually accumulating carbon in grassland soils. Management of grassland, if not over-used, can enhance the carbon sequestration rate, but upon conversion of grassland to cropland no additional carbon is accumulating (Soussana et al., 2007). This effect is modelled in CAPRI by deriving simple emission factors for natural grassland, managed permanent grassland, arable land sown with grass or legumes, and other cropland from the data presented in the literature. Land use emissions/removals from carbon sequestration are then calculated as the difference from the emissions on these three types of managed agricultural land considered and natural grassland. Only this difference is credited or debited to the current land use. The concept is illustrated in Figure ES3.

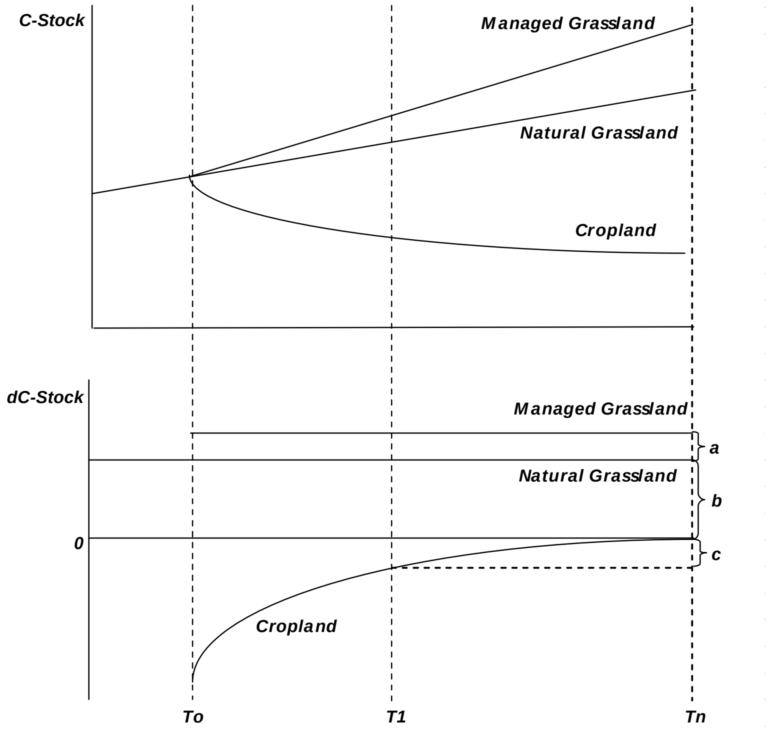

Figure ES3. Schematic illustration of the implementation of carbon sequestration in CAPRI. At time t1 natural grassland is converted to either managed grassland or cropland. The carbon sequestration rate of the land use increases for the grassland (a), but drops to zero (b) for the cropland. This is shown in lower panel indicating the changes in carbon stock with time. In the cropland, an equilibrium carbon stock will be established after some time. These emissions (c) are caused by land use change.

Product-based emissions are calculated for feed transport, using emission factors from Kraenzlein (2008) and an own estimate of transport distances, and land use change. For land use change, we consider CO_2 emissions from carbon stock changes in below and above ground biomass and dead organic matter, CO_2 emissions from soil carbon stock changes, and CH_4 and N_2O emissions from biomass burning. For all land use change emission sources, a Tier 1 methodology of the IPCC 2006 guidelines is applied. One critical element for estimating GHG emissions caused by land use change is how to decide which share of land use change to be assigned to crop production and specific crops. A review of available data sources revealed the lack of data sets covering consistently global land use change from forests and savannas. Therefore, a simplified approach was implemented: Based on time series of the FAO crop statistics, the change of total cropland area and (the change of) the area for single crops was calculated for a ten year period (1999-2008) in all EU countries and non-EU country blocks used in the CAPRI model. For those regions where the total cropland area has increased the additional area was assigned to crops by their contribution to area increases. The area assigned to a certain crop was divided by the total production of the crop in the region over the same time period, in order to derive the area of cropland expansion per kg of the crop product. For the origin of converted land, three scenarios were defined that should span the space of possible outcomes. In the first scenario we assume that all converted land was grassland and savannas with lower carbon emissions than forests. The second scenario applies a more likely mix of transition probabilities, while Scenario III can be considered as a maximum emission scenario.

Conversion of activity-based emissions to product-based emissions and the carrying of the emissions throughout the supply chain to the production of the functional unit at the farm gate is calculated on the basis of the nitrogen content for all emission sources with the exception of CH_4 emissions from dairy cattle enteric fermentation and manure management (for which energy requirement for lactation and pregnancy is used). Moreover, in the LCA emissions caused by the application of manure are entirely assigned to livestock production. However, part of the manure is applied on crops are not used for feed thus saving an analogue amount of mineral fertilizer. We account for these emissions with the system expansion approach (see ISO, 2006). The emissions saved are quantified and credited to the livestock product in the respective emission categories (application and production of mineral fertilizers).

Comparison of EU livestock GHG emissions derived by CAPRI with official GHG inventories

For the comparison of activity-based GHG emissions calculated in the GGELS project (taking into account only emissions directly created during the agricultural production process) with official national GHG emissions submitted to the UNFCCC, we selected the latest inventory submission of the year 2010 (EEA, 2010), using the data reported for the year 2004, the base year selected also for the CAPRI calculations.

Differences in basic input parameters, such as animal numbers and mineral fertilizer application rates are limited, since both are based on the official numbers of livestock statistics. However, on the one hand EUROSTAT data are not always in line with national statistical sources used by national inventories, and on the other hand CAPRI changes input data if they are not consistent with each other. Moreover, for some animal activities CAPRI does not use livestock numbers but numbers of the slaughtering statistics. Therefore, some differences exist, especially in case of swine, sheep and goats, where CAPRI generally uses lower numbers than the national inventories. This has to be kept in mind when looking at the results in later sections.

In some cases results differ substantially between CAPRI and the inventory submissions, which can be related to three different reasons: First, the approach of CAPRI and the national inventories is not always the same. Especially, the MITERRA approach, which is applied for the calculation of nitrogen emissions in the CAPRI model, differs substantially from the IPCC approach usually applied in the inventories. In CAPRI the excretion is not an exogenous parameter but is calculated as the difference between nitrogen intake and nitrogen retention of animals. For cattle and poultry deviations are generally low, while for swine, sheep and goats the differences are larger (see Figure ES5). In case of swine the usually higher CAPRI values partly compensate the lower livestock numbers.

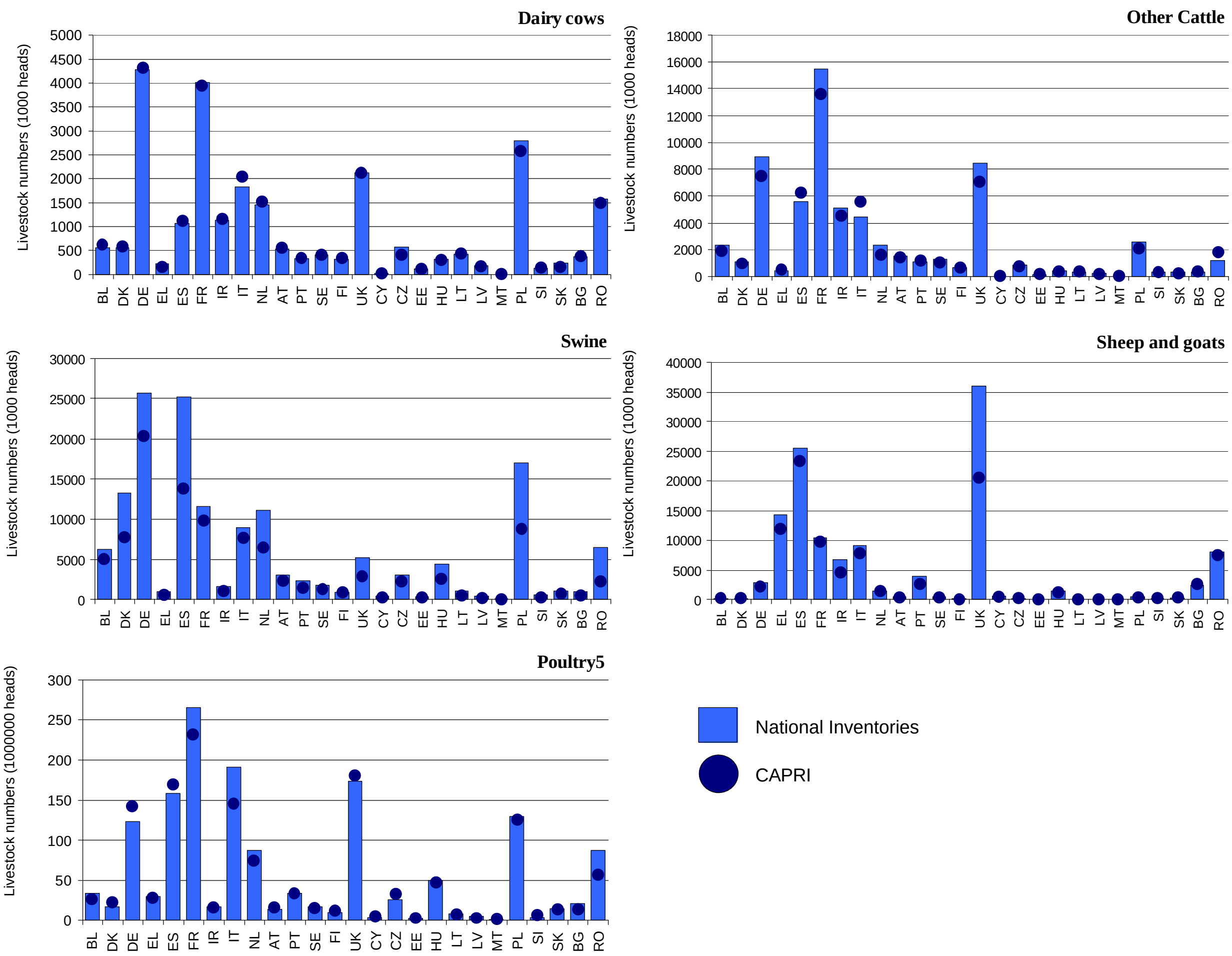

Figure ES4. Comparison of livestock numbers used in National Inventories to the UNFCCC for the year 2004 (EEA, 2010) and livestock numbers used in CAPRI

Second, most countries base their inventory calculations on the IPCC guidelines 1996, while CAPRI uses parameters of the most recent guidelines of the year 2006. In some cases emission factors and other parameters suggested by the IPCC changed considerably between 1996 and 2006, leading to corresponding changes in the estimation of emissions. Finally, apart from different approaches and different parameters due to changes in the IPCC guidelines, also other input data can impact on the results. This could be i.e. differences in livestock numbers, the distribution of manure management systems or time spent on pastures, average temperatures, or more technical data like fertilizer use, milk yields, live weight, nutrient contents, nitrogen excretion etc., which are partly assumed and partly already an output of calculation procedures in the CAPRI model. Since the national inventories use other input data some differences in the results are not surprising. For example, differences in estimated CH_4 emissions from enteric fermentation are mainly due to different emission factors for dairy and non-dairy cattle, since other animal categories play a less important role with respect to total emissions from enteric fermentation. The following factors can be identified as potential reasons for the deviations. First, for cattle (Tier 2 approach) CAPRI calculates the digestible energy endogenously, while most inventory reports use default values. Secondly, in the inventories most countries apply a methane conversion factor of 6% (default value according to IPCC 1997, see IPCC 1996), while CAPRI uses 6.5% (default value of IPCC 2006, see IPCC, 2006), leading to higher emission factors in CAPRI of around 8%. Thirdly, animal live weight impacts directly on net energy requirement, but can only be compared for dairy cows. CAPRI generally assumes a live weight of 600 kg, while national inventories use different values ranging from 500 to 700 kg. However, a simple regression suggests that live weight is not a key factor for the generally higher CAPRI values. Finally, there are differences in the weight gain and milk yields. While assumptions on the weight gain are not available in the inventory submissions and, therefore, cannot be compared, milk yields are usually higher in CAPRI than in the national submissions, favouring higher emission factors in case of dairy cows.

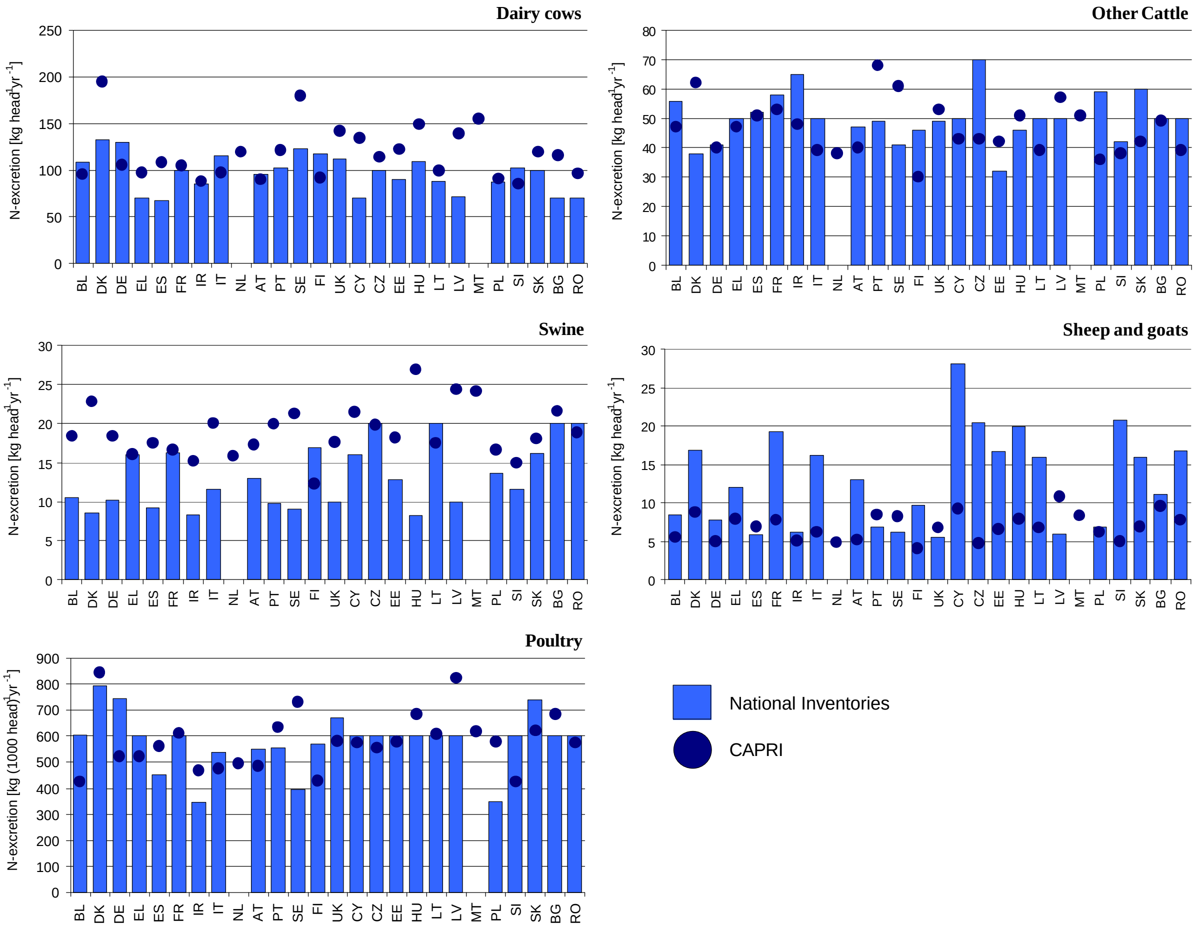

Figure ES5. Comparison of N-excretion data used in National Inventories to the UNFCCC for the year 2004 (EEA, 2010) and N-excretion data calculated with CAPRI

For EU-27, CAPRI calculates total agricultural sector emissions of 378 Mio tons of $CO_{2\text{-eq}}$, which is 79% of the value reported by the member states (477 Mio tons, biomass burning of crop residues and CH_4 emissions from rice production not included). On member state level this ranges between 54% in Cyprus and 127% in Denmark. Therefore, Denmark is the only member state for which CAPRI estimates total emissions higher than the NIs. With respect to the different emission sources, the relation of CAPRI emissions to NIs are: 103% for CH_4 emissions from enteric fermentation, 54% for CH_4 and 93% for N_2O emissions from manure management, 92% for N_2O emissions from grazing animals, 81% for N_2O emissions from manure application to managed soils, 89% for N_2O emissions from mineral fertilizer application, 87% for N_2O emissions from crop residues, 89% for indirect N_2O emissions following volatilization of NH_3 and NO_X, 11% of N_2O emissions following Runoff and Leaching of nitrate, and 97% of emissions from the cultivation of organic soils.

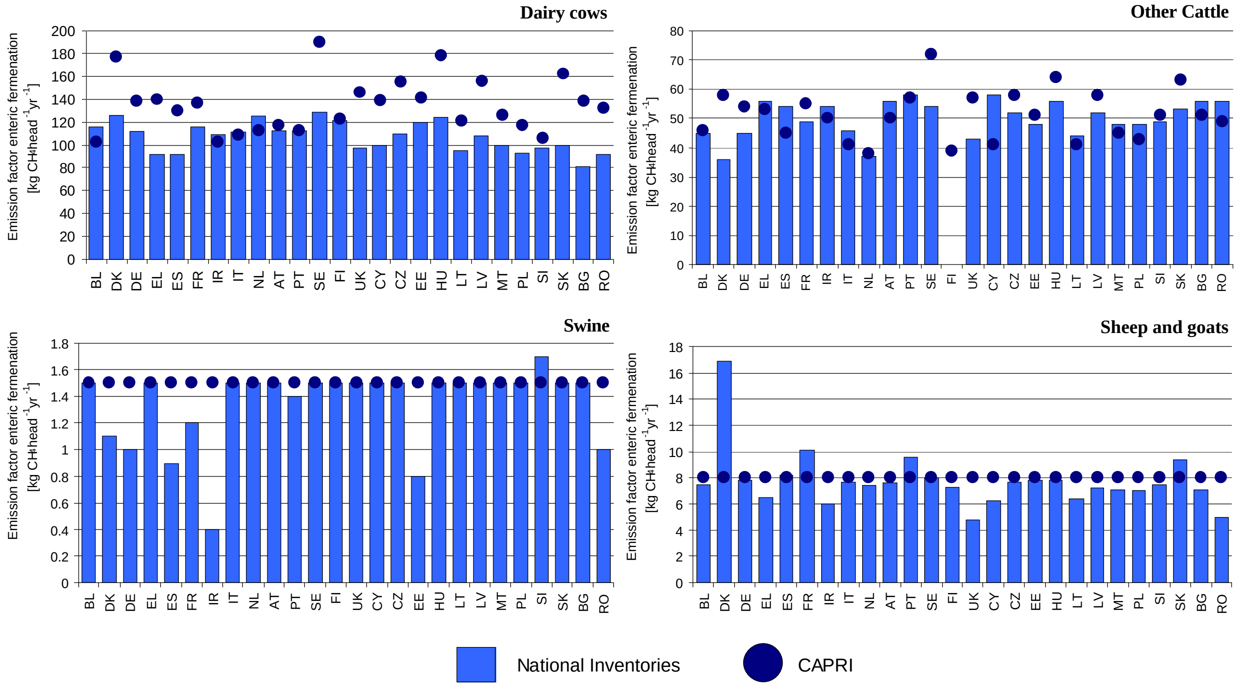

Figure ES6. Comparison of emission factors for enteric fermentation in dairy and non-dairy cattle, swine, and sheep and goats used in National Inventories to the UNFCCC for the year 2004 (EEA, 2010) and the emission factors calculated (in case of dairy and non-dairy cattle) or used (in case of swine and sheep and goats) in CAPRI

Quantification of GHG emissions of EU livestock production in form of a life cycle assessment (LCA)

The product based emissions calculated with the LCA approach (including all emissions directly or indirectly caused by the livestock production) are based on the activity based emissions. However, for several reasons the total of product based emissions does not exactly match the total of activity based emissions. First, as mentioned above, for some emission sources the product related emission factors do not or not only contain emissions directly created by the livestock, but (also) those related to inputs. Therefore, for those emission sources a direct comparison is not possible due to a different regional scope (emissions from imported products) and a different sectoral scope (emissions from energy production and use, industries, land use change etc. related to livestock and feed production) Secondly, the life cycle assessment focuses on the emissions caused by a certain product in a certain year. Animal products, however, are not always produced in one year. Let’s assume the product is beef. Then one kg of beef produced in the year 2004 contains not only emissions of i.e. the respective fattening activity in the same year but also the emissions for raising the young animals needed as input to the activity. In contrast to the activity based approach, for beef emissions in the year 2004 it is not relevant how many young calves have been raised in the same year, but how many calves are in the product output of the year 2004. Since livestock numbers change from year to year a deviation of activity and product based emissions is expectable, as young animals are not considered as final animal product in this study.

Results are presented for the greenhouse gases CH_4, N_2O and CO_2 and the non-greenhouse gases NH_3 and NO_X, for 21 different emission sources, 7 animal products (beef, cow milk, pork, sheep and goat meat and milk, eggs and poultry meat), 218 European regions (usually NUTS 2 regions), 26 member states (Belgium and Luxemburg are treated together) and in case of beef and cow milk 14 livestock production systems (see description of livestock typology in chapter 2). The base year for the estimation is 2004.

According to CAPRI calculations the total GHG fluxes of European Livestock production amount to 661 Mio tons of $CO_{2\text{-eq}}$ (see Figure ES7). 191 Mio tons (29%) are coming from beef production, 193 Mio tons (29%) from cow milk production and 165 Mio tons (25%) from pork production, while all other animal products together do not account for more than 111 Mio tons (17%) of total emissions. 323 Mio tons (49%) of total emissions are created in the agricultural sector (see Figure ES8), 136 Mio tons (21%) in the energy sector, 11 Mio tons (2%) in the industrial sector and 191 (29%) Mio tons are caused by land use and land use change (Scenario II), mainly in Non-European countries. Total emissions from land use and land use change, according to the proposed scenarios, range from 153 Mio tons (Scenario I) to 382 Mio tons (Scenario III). The weight of land use (carbon sequestration and CO_2 emissions from the cultivation of organic soils) and land use change varies greatly among the countries, with little emissions from land use change for example in Romania and Finland, and little emissions from land use in Greece, Latvia, and the UK. This is mainly due to the carbon removal credited to the grassland used in these countries which offsets most of the foregone carbon sequestration for the cultivation of feed crops. In Ireland, the enhancement of the carbon sequestration in grassland is larger than the reduced carbon sequestration for cropland.

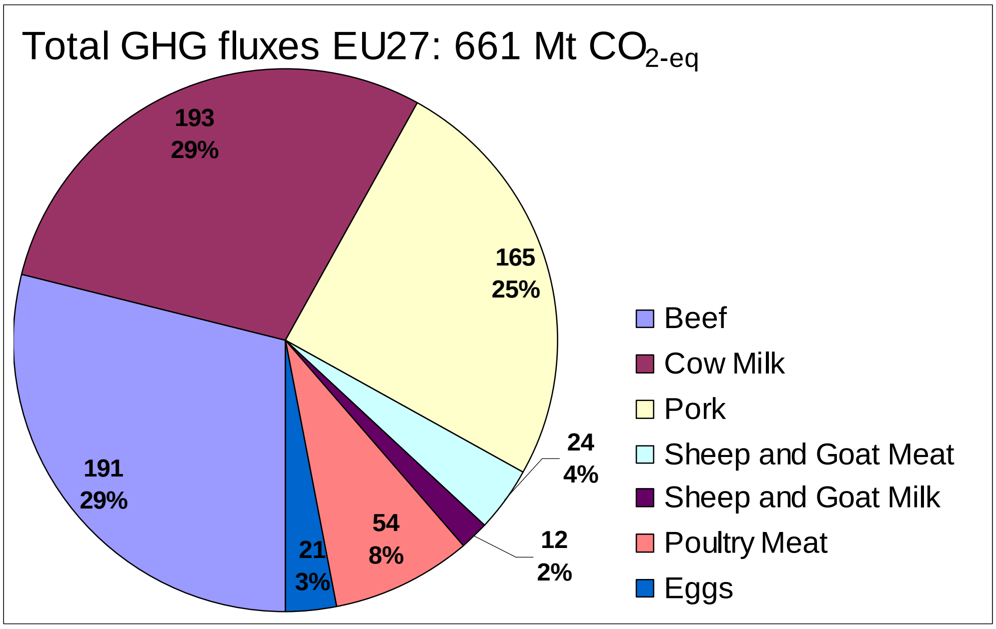

Figure ES7. Total GHG fluxes of EU-27 livestock production in 2004, calculated with a cradle-to-gate life-cycle analysis with CAPRI

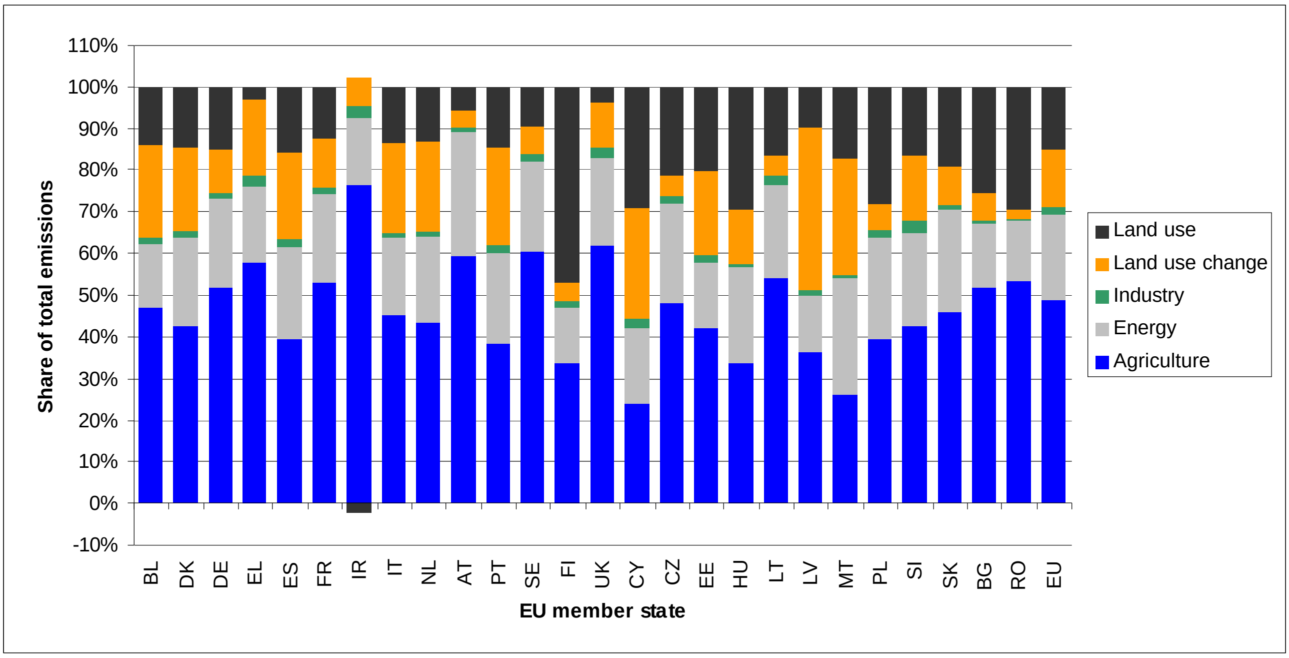

Figure ES8. Share of different sectors on total GHG emissions. In this graph, the land use and the land-use change sector are depicted separately.

181 Mio tons (27%) of total emissions assigned to the livestock sector are emitted in form of methane, 153 Mio tons (23%) as N_2O, and 327 Mio tons (50%) as CO_2 (Scenario II), ranging from 289 Mio tons (Scenario I) to 517 Mio tons (Scenario III).

On EU average livestock emissions from the agricultural sector (emissions from energy use, industries and land use change not included) estimated by the life cycle approach amount to 85% of the total emissions from the agricultural sector estimated by the activity based approach, and 67% of the corresponding values submitted by the member states (National Inventories, see Figure ES9). This share ranges from 63% to 112% (48% to 120%) among EU member states. Adding also emissions from energy use, industries and LULUC (Scenario II) livestock production creates 175% of the emissions directly emitted by the agricultural sector (according to CAPRI calculations) or 137% respectively (according to inventory numbers).The share of livestock production (LCA) in total emissions from the energy sector (inventories) is 3.3%, the share of mineral fertilizer production for livestock feeds (LCA) in total industrial sector emissions (inventories) 2.6 percent. Finally, the livestock sector (LCA results, land use and land use change excluded) accounts for 9.1% of total emissions (all sectors) according to the inventories, considering land use change, the share increases to 12.8%.

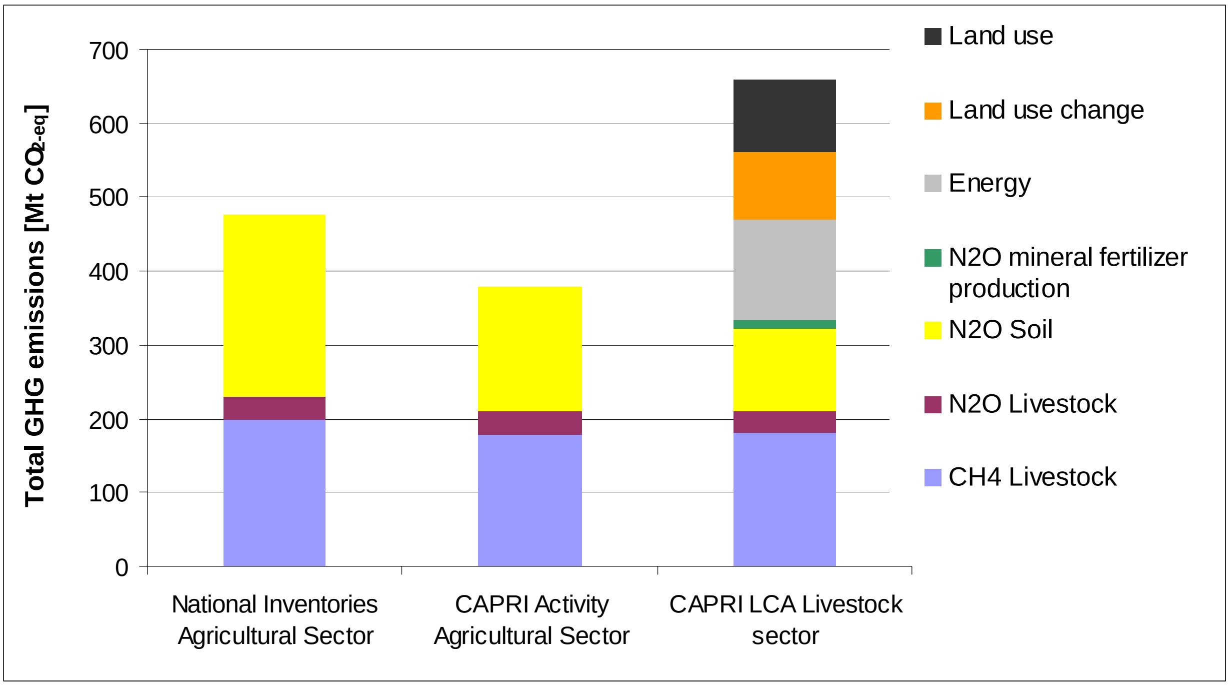

Figure ES9. Total GHG fluxes of EU-27 in 2004 of the agriculture sector as submitted by the national GHG inventories to the UNFCCC (left column, EEA, 2010), calculated with CARPI for the IPCC sector agriculture with the CAPRI model (middle column), and calculated with a cradle-to-gate life-cycle analysis with CAPRI (right column). Emissions from livestock rearing are identical in the activity-based and product-based calculation. Soil emissions include also those that are 'imported' with imported feed products. The LCA analysis considers also emissions outside the agriculture sector.

On product level the Total of GHG fluxes of ruminants is around 20-23 kg $CO_{2\text{-eq}}$ per kg of meat (22.2 kg for beef and 20.3 kg per kg of sheep and goat meat) on EU average, while the production of pork (7.5 kg) and poultry meat (4.9 kg) creates significantly less emissions due to a more efficient digestion process and the absence of enteric fermentation. In absolute terms the emission saving of pork and poultry meat compared to meat from ruminants is highest for methane and N_2O emissions, while the difference is smaller for CO_2 emissions. Nevertheless both pork and poultry meat production creates lower emissions also from energy use and LULUC. The countries with the lowest emissions per kg of beef are as diverse as Austria (14.2 kg) and the Netherlands (17.4 kg), while the highest emissions are calculated for Cyprus (44.1 kg) and Latvia (41.8 kg), due to low efficiency and high LULUC-emissions from domestic (Latvia) cropland expansion or high import shares (Cyprus).

Emissions per kg of cow milk are estimated at 1.4 kg of $CO_{2\text{-eq}}$ on EU average, emissions from sheep and goat milk at almost 2.9 kg. However, data quality in general is less reliable for sheep and goat milk production than for cow milk production, which is important for the assignment of emissions. The lowest cow milk emissions are created in Austria and Ireland (1 kg), the highest in Cyprus (2.8 kg) and Latvia (2.7 kg). Figure ES10 shows average product-based emissions for the seven animal products considered for EU-27 member states.

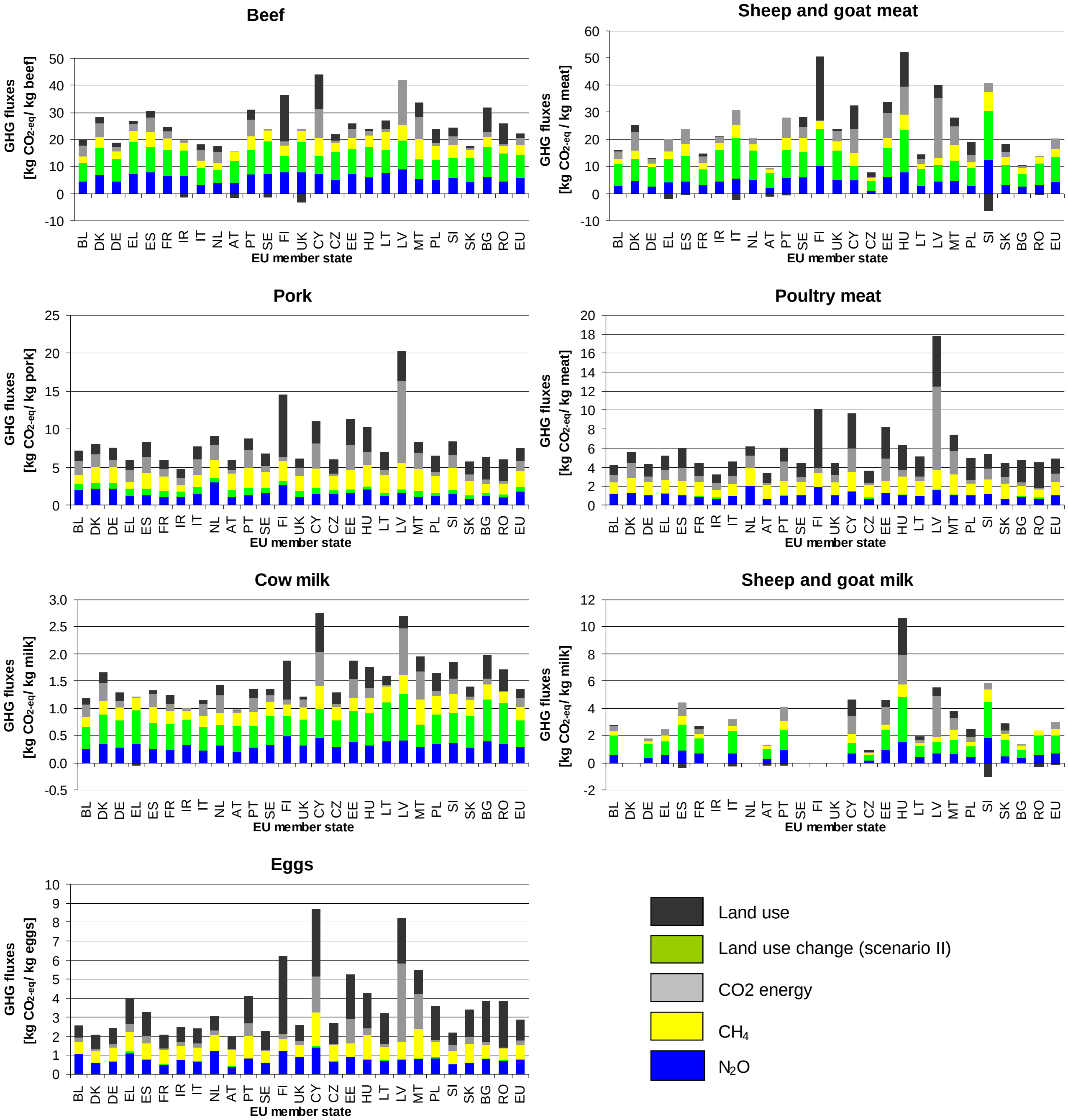

Figure ES10. Total GHG fluxes of EU-27 livestock products in 2004, calculated with a cradle-to-gate life-cycle analysis with CAPRI

Technological abatement measures for livestock rearing emissions

Technically achievable mitigation solutions in the EU livestock sector, based on the reviewed literature data, are estimated to achieve a reduction of GHG emissions of about 55-70 Mt $CO_{2\text{-eq}}$ yr^{-1}, or 15-19% of current GHG emissions. However, it is well recognized that large uncertainties exists around indicated mitigation potentials in the sector. On the one hand, the net impact of specific abatement measures depends on the baseline climates, soil types and farm production systems being addressed. On the other hand, the number of studies that actually quantify GHG reductions is rather limited, both in terms of regions and mitigation measures covered. Because of the variability in systems and management practices and because of the lack of more detailed country or region specific data, a more detailed analysis would be required to arrive at a robust estimate for mitigation in Europe thus the value given can only be a very rough estimate. Furthermore, many measures would require investments, others require changes in common practice and yet others require technological. The full potential of most of the measures outlined could take several decades past 2020 to be achieved.

In particular for soil emissions and enteric fermentation, more research is needed assessing trade-off and feed-back effects. Emission reductions have already been achieved through implementation of the nitrate directive on Nitrate Vulnerable Zones (NVZs) and an extension of this regulation on all agricultural land is likely to lead to positive results. More information exists in relation to actions that can be applied to manure management, and in general to animal waste management systems. In general the methane component of these emissions can be captured and flared in large proportions, for power or otherwise. The numbers indicated by the studies reviewed above are often uncertain in the net overall mitigation for both CH_4 and N_2O, however assuming full deployment of current technologies, technical potentials found in these studies appear to be about 30% of current emissions from manure management, provided anaerobic digestion and composting are key components of such strategies.

The CAPRI model was used to assess the impact of selected technological abatement measures for the production structure of the base year 2004. We define the technical reduction potential of a measure as the reduction (or increase) of emissions compared to the base year results presented above, if the measure would be applied on all farms. Therefore, the potential must not be interpreted as an estimation of a realistic implementation rate of the respective measure. The selection of technological measures was mainly based on the availability of reduction factors (for all gases) and the applicability of the available information to the CAPRI model, and the selected technologies are in first instance related to the reduction of NH_3 emissions. The following measures were assessed: (i) animal house adaptations; (ii) covered outdoor storage of manure (low to medium efficiency); (iii) covered outdoor storage of manure (high efficiency); (iv) low ammonia application of manure (low to medium efficiency); (vi) low ammonia application of manure (high efficiency); (vii) urea substitution by ammonium nitrate for mineral fertilizer application; (vii) no grazing of animals; and (viii) biogas production for animal herds of more than 100 LSU (livestock units).

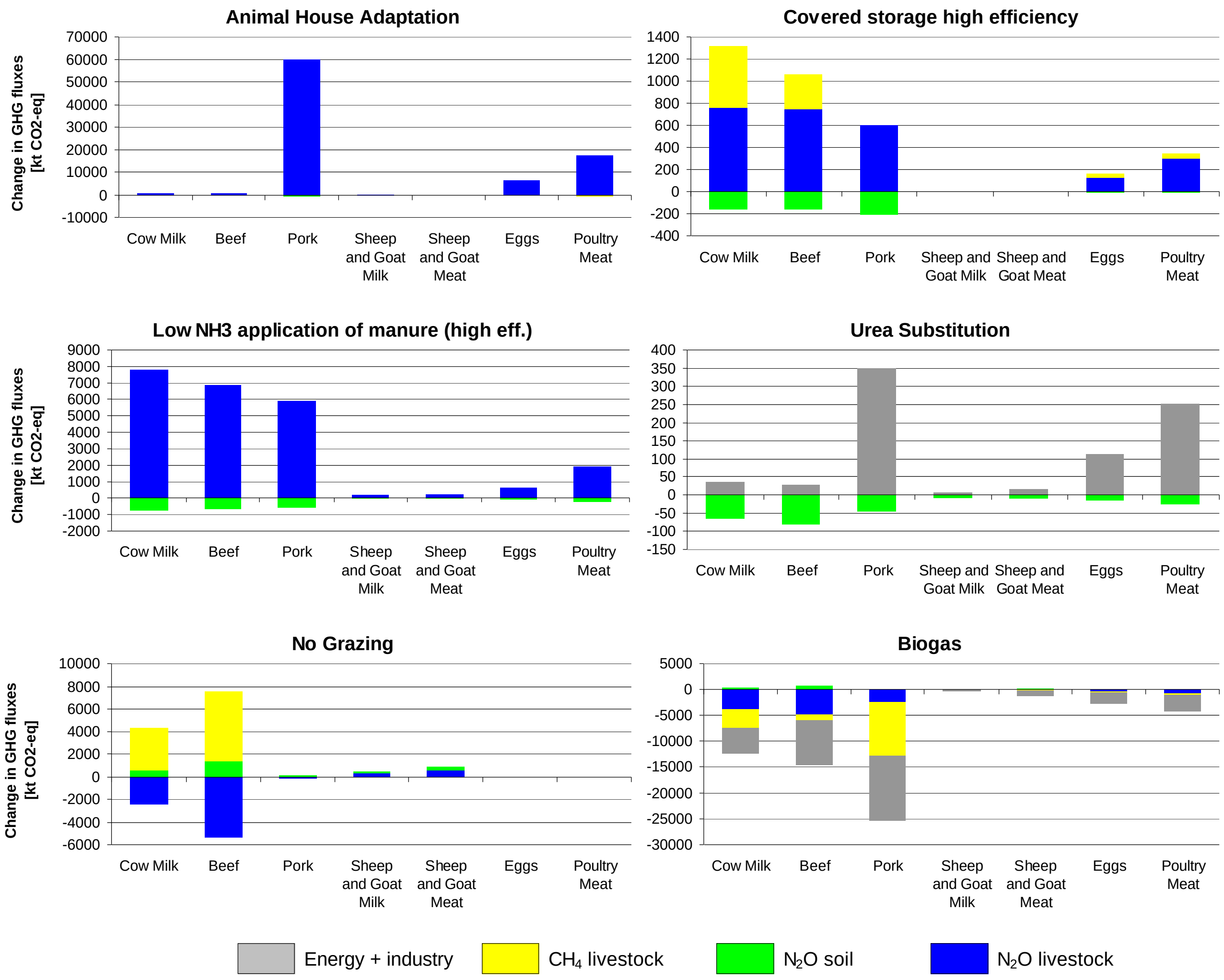

Figure ES11. Impact of selected technological abatement measures, compared with the reference situation for the year 2004, if the measure would be applied by all farms, calculated with a cradle-to-gate life-cycle analysis with CAPRI

Figure ES11 shows an overview of the simulated impact of the application of the selected measures (only high-efficiency solutions for outdoor storage and application of manure) on GHG emissions, differentiated by CO_2 emissions from energy, CH_4 emissions from livestock, N_2O emissions from livestock (including manure application and grazing) and N_2O emissions from soil (indirect emissions following volatilization or leaching of reactive nitrogen). Other GHG sources considered in this study are not affected by the selected measures (e.g. application of mineral fertilizer, emissions from crop residues) or their effect is too complex and could not be simulated with the model at hand (e.g. changes in crop productivity and consequences on land use and land use change). Trade-offs between emissions from manure management and soil are clearly shown if reducing NH_3 emissions by covering outdoor manure storages or applying low-NH_3 manure application techniques, which generally lead to higher N_2O fluxes with the exception of indirect N_2O emissions following NH_3 volatilization. Urea substitution reduces NH_3 emissions, and has a positive effect in reducing also soil N_2O emissions, but at the cost for higher emissions from the manufacturing of mineral fertilizers. The ‘no grazing’ scenario gives interesting results, by over-compensating reduction of N_2O emissions from manure with increasing CH_4 emissions from livestock which is due to the different quality of grass that is grazed and grass that is cut and fed to the animal in housings. However, many effects could not be considered in this scenario, i.e. the carbon sequestration model implemented is with the differentiation of only three land uses too simple to cover changes in carbon sequestration; the feeding ration is kept constant; changes in energy use have not been considered. Nevertheless, this exercise shows that many effects at different places determine the overall outcome of such measures and that one has to be careful with too simplified conclusions.

On the basis of the implementation of the effect of biogas installations for large farms >100 livestock units and liquid manure systems, this measure appears to have largely positive effects on GHG emissions, reducing CH_4 and N_2O emissions from manure management but also following application of the digested slurry. Additionally, carbon credits are given for production of energy.

Prospective overview of EU livestock emission – an exploratory approach

One of the objectives within the CAPRI-GGELS project was to assess the GHG and ammonia emission reduction potential of a selected number of policy options. Therefore the possible future evolution of EU livestock emissions is assessed through the simulation of scenarios including expected macro- and micro-economic changes. This task differs from other parts of the report as the calculation of agricultural emission inventories is based on agricultural activity, i.e. it is not following a life cycle approach (LCA). The reason for this is that the LCA in the CAPRI model is not yet operational to be used for policy scenarios. *The mitigation policy scenarios proposed and analysed within this project are all exploratory*, i.e. it is intended to explore what could happen if policies would be implemented that explicitly force farmers in the EU-27 to reach certain GHG emission reduction targets. It has to be stressed that all policy scenarios are rather hypothetical and do not necessarily reflect mitigation policies that are already agreed on, or are under formal discussion.

Apart from the reference scenario, which assumes that GHG emissions continue to be determined as in the past, the policy scenarios are characterised by a target of 20% GHG emission reduction in the year 2020 compared to EU-27 emissions in the base year 2004. The examined policy scenarios are a) *Reference or Baseline Scenario (REF)*, which presents a projection on how the European agricultural sector (and thus GHG emissions of the agricultural sector) may develop under the status quo-policy (i.e. full implementation of the Health Check of the Common Agricultural Policy). The REF Scenario serves as comparison point in the year 2020 for counterfactual analysis of all other scenarios, b) *Emission Standard Scenario (STD):* this scenario is linked to an emission abatement standard homogenous across MS; c) *Emission Standard Scenario according to a specific Effort Sharing Agreement for Agriculture (ESAA):* this scenario is linked to emission abatement standards heterogeneous across MS, with emission 'caps' according to a specific effort sharing agreement; d) *Livestock Tax Scenario* (*LTAX)* which introduces regionally homogenous taxes per ruminants; and e) *Tradable Emission Permits Scenario according to an Emission Trading Scheme for Agriculture (ETSA):* This scenario is linked to a regionally homogenous emission 'cap' set on total GHG emissions in MS. According to this 'cap' tradable emission permits are issued to farmers and trade of emission permits is allowed at regional and EU-wide level.

In the reference scenario no explicit policy measures are considered for GHG emission abatement, but scenario results show a reduction in total GHG emissions in almost all EU-27 MS in the year 2020, with a somewhat higher reduction in the EU12 compared to EU15. However, given that GHG emissions in EU15 in the base year are almost five times higher than in EU12, the reduction in EU15 is more significant in absolute terms. For EU-27 the emission reduction in $CO_{2\text{-eq}}$ is projected to be -6.8% compared to the reference year, with methane emissions being reduced by -15% and emissions of nitrous oxide by -0.4%.

The four defined GHG emission abatement policy scenarios could be designed to almost achieve the reduction goal of 20% emission reduction compared to the reference year (+- 0.01 error margin tolerated). The emission reduction effect per country in each scenario is quite different from the EU-27 average depending on the production level and the composition of the agricultural activities. MS that are projected to already achieve a 20% GHG emission reduction in the baseline (i.e. without additional policy measures) would clearly benefit from an emission permit trading scheme as they are free to decide if they would increase their emissions at no additional costs or sell their emission permits to other MS. For the scenarios STD, ESAA and ETSA the projected decrease in production activities leads to higher prices and therefore a higher agricultural income could be expected. In all policy scenarios the largest decreases in agricultural activities are projected to take place at beef meat activities. The LTAX scenario especially influences the milk and beef activities, with strong decreases in herd sizes and income.

When emission leakage is included in the calculation, it can be observed that the effective emission reduction commitment in the EU is diminished due to a shift of emissions from the EU to the rest of the world (mainly as a result of higher net imports of feed and animal products). Emission leakage is projected to be highest in the LTAX scenario. This is due to increased beef production in the rest of the world in order to meet demand in the EU.

The following table summarises the GHG emissions (MMt $CO_{2\text{-eq}}$) and emission reductions (%) for all scenarios including emission leakage.

	BAS	REF	STD	ESAA	ETSA	LTAX
Total GHG emissions EU27	476.1	443.5	382.7	385.1	384.0	385.1
% reduction to BAS (2003-2005)		*-6.8%*	*-19.6%*	*-19.1%*	*-19.3%*	*-19.1%*
Net increase in emissions in rest of the world due to emission leakage		0.0	9.2	8.4	6.0	19.9
% reduction to BAS (2004)		*-6.8%*	*-17.7%*	*-17.3%*	*-18.1%*	*-14.9%*

Ancillary assessments

This study includes some ancillary assessments, which are thought to round the picture of the impact of livestock products, knowing however that the assessment is still far from being complete. The two additional assessments are exemplarily for two aspects that have not been covered in the main part of the study: (i) environmental impacts other than GHG and NH_3 emissions and (ii) post-farm gate emission and the impact of livestock products from a consumer perspective.

To this end, we have selected biodiversity as one important aspect of non-GHG and NH_3 environmental consequences of livestock production and the estimation of emissions for a few – important – imported animal products from non-EU countries. Note that this assessment has been performed on the basis of a literature review and the results are therefore not directly comparable with the results for European livestock production obtained with the CAPRI model.

Overview of the impact of the livestock sector on EU biodiversity

The overview of livestock impacts on EU biodiversity is based on extensive research of European of the currently available source materials. Impacts are analysed with reference to the present situation in the livestock sector. The analysis is not extended, however, to estimate the impacts of the mitigation measures or the modelling of policy scenarios.

Over the centuries, traditional agricultural land use systems, including livestock production and mixed farming, have fostered species-rich, diverse ecosystems and habitats with a high conservation value. Nowadays, semi-natural habitats in farmland are European biodiversity hotspots.

The intensification of agriculture in the second half of the 20th century has contributed to biodiversity decline and loss throughout Europe, major factors being pollution and habitat fragmentation and loss. Major impacts from animal production are linked to excess of reactive nitrogen, with current estimates attributing up to 95% of NH_3 emissions to agriculture (Leip et al., 2011). This causes acidification and eutrophication of soils and water and subsequent depauperation of plant assemblages and reduction of the abundance of fauna linked to them. A number of valuable European habitats have been shown to be seriously threatened by N deposition, including fresh waters, species-rich grasslands and heathlands. Habitat loss and fragmentation negatively affects biodiversity on all levels: genetic, species and ecosystem. However, quantifying impacts of those factors separately for the livestock sector is very difficult or impossible, due to the complexity of ecological interactions between biodiversity components and current gaps of knowledge of cause-effects links between farming practices and biodiversity.

On the other hand, many habitats important for biodiversity conservation have been created by and are still inherently linked to livestock production, in particular grazing. For example, in the Mediterranean region of Europe grazing is essential for the prevention of shrub encroachment. Extensive grazing is considered vital for maintaining many biodiversity-rich habitats and High Nature Value farmland in Europe. Grazing is also critical for maintaining many of Europe’s cultural landscapes and sustaining rural communities.

Estimation of emissions of imported animal products

GHG emissions were estimated for the three most important animal products imported to the European Union, in terms of quantity: sheep meat from New Zealand, beef from Brazil and poultry meat imported from Brazil. The methodology used does not follow the procedures developed for the assessment GHG emissions from livestock production systems in the EU-27, but relies on a careful analysis of literature data. A food-chain with a narrow definition of the boundaries was applied, neglecting emissions from meat processing and fossil fuel consumption for construction of machinery or electricity production. Included were emissions from housing and manure management and soil emissions from feed production, as well as emissions from the manufacturing of fertilizer, on-farm energy use and emissions from animal products transport, as shown in Table ES2.

Table ES2: Overview of emission sources for each of the import flows. 'X' denotes that the emission source is included, 'NO' denotes not occurring and 'NR' denotes not relevant (minor emissions).

Emission source	**Beef BRA**	**Chicken BRA**	**Sheep NZL**	**Compounds**
Use of fertilizers (pastures and feed production)	NR	X	X	N_2O, NH_3
Manufacturing of fertilizers	X	X	X	CO_2, N_2O
Lime application (pastures and feed production)	NR	X	X	CO_2
Crop residues left to soils (feed production)	NO	X	NO	N_2O
Feed transport	NO	NR	NO	CO_2
Land-use change due to grasslands expansion/cropland expansion for feed production	X	X	NR	CO_2
On-farm energy use	X	X	X	CO_2
Enteric fermentation	X	NO	X	CH_4
Manure management (storage)	NO	X	NO	NH_3, N_2O, CH_4
Manure deposition by grazing animals	X	NO	X	NH_3, N_2O, CH_4
Application of manure to agricultural soils	NO	X	NO	NH_3, N_2O
Indirect N_2O from leaching and runoff	X	X	X	N_2O
Indirect N_2O from deposition of NH_3	X	X	X	N_2O
Transport of animal products	X	X	X	CO_2

Total GHG emissions in kg $CO_{2\text{-eq}}$ per kilogram of meat varies between 1.2 kg $CO_{2\text{-eq}}$/kg meat for chicken from brazil over 33 kg $CO_{2\text{-eq}}$/kg meat for sheep meat from New Zealand to 80 kg $CO_{2\text{-eq}}$/kg meat for beef from Brazil (see Table ES3). The latter value includes emissions caused by land use changes, which have been estimated based on increases in pasture area in Legal Amazon, meat production, and import of beef meat to Europe. The resulting GHG emissions, 31 kg CO_2/kg meat, contribute with 29% to total emissions from beef imports from Brazil, second to CH_4 emissions from enteric fermentation with 45% of total emissions. However, the estimate of land use change (LUC) related emissions is highly uncertain and must be used with extreme caution.

Even without considering LUC emissions, beef imported from Brazil has the highest carbon footprint of the products assessed, which is due to the low productivity of Brazilian beef compared with sheep in New Zealand causing both longer turn-over times and also lower digestibility of the feed and thus higher CH_4 emissions.

While for the two ruminants considered CH_4 from enteric fermentations is the most important GHG source, on-farm energy use plays the biggest role for chicken from Brazil (34% of total emissions) followed by emissions from fertilizer manufacturing. Overall, chicken imports do not contribute to GHG emissions from imported animal products, being with 0.2 Mt $CO_{2\text{-eq}}$ much lower than emissions from imported sheep meat from New Zealand (6.4 Mt $CO_{2\text{-eq}}$) or beef meat from Brazil (8.7 Mt $CO_{2\text{-eq}}$ or 14.4 Mt $CO_{2\text{-eq}}$ including LUC emissions).

Table ES3: Comparison of emissions of the three most important import products.

	Sheep NZE	**Beef from BRA (without LUC)**	**Chicken from BRA**
GHG emissions (kg $CO_{2\text{-eq}}$/kg meat)	33	80 (48)	1.2
GHG emission from product imports (million ton $CO_{2\text{-eq}}$)	6.4	14.4 (8.7)	0.2
Most important GHG sources	-Enteric fermentation (63%) -Manure in pasture (20%)	-Enteric fermentation (45%) -Land-use change (39%) -Manure in pasture (15%)	-On-farm energy use (34%) -Fertilizer manufacture (16%) -N fertilizer use (12%)
NH_3 emissions (kg NH_3/kg meat)	0.1	0.1	0.02
NH_3 emission total of imported products (kton NH_3/kg meat)	17	20	4.2
Most important NH_3 sources	-Manure in pasture (73%) -N fertilizer use (27%)	-Manure in pasture (100%)	-Manure management (56%) -N fertilizer use (24%)

Conclusions

The project "*Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions*" (GGELS) has the objective to provide a thorough analysis of the livestock sector in the EU with a specific focus on the quantification and projection of GHG and NH_3 emissions. Calculations were done with the CAPRI model which has been completely revised in order to reflect the latest scientific findings and agreed methodologies. The gases covered by this study are CH_4, N_2O, CO_2, NH_3, NO_X and N_2.

The main results of this study can be summarized in the following bullets:

- Total GHG fluxes of European livestock production including land use and land use change emissions amount to 661 Mt $CO_{2\text{-eq}}$. 191 Mt $CO_{2\text{-eq}}$ (29%) are from beef production, 193 Mt $CO_{2\text{-eq}}$ (29%) from cow milk production and 165 Mt $CO_{2\text{-eq}}$ (25%) from pork production, while all other animal products together do not account for more than 111 Mt $CO_{2\text{-eq}}$ (17%) of total emissions.

- According to IPCC classifications, 323 Mt $CO_{2\text{-eq}}$ (49%) of total emissions are created in the agricultural sector, 136 Mt $CO_{2\text{-eq}}$ (21%) in the energy sector and 11 Mt $CO_{2\text{-eq}}$ (2%) in the industrial sector. 99 (15%) Mt $CO_{2\text{-eq}}$ are related to land use (CO_2 emissions from cultivation of organic soils and reduced carbon sequestration compared to natural grassland) and 91 Mt $CO_{2\text{-eq}}$ to land use change, mainly in Non-European countries.

à These results are assigned with considerable uncertainty. Particularly data for assessing land use change and changing carbon sequestration are uncertain. For land use change, three scenarios have been designed that should span the range of possible emissions. Accordingly, emissions from land use change are between 54 Mt $CO_{2\text{-eq}}$ and 283 Mt $CO_{2\text{-eq}}$

à Compared with official GHG inventories submitted to the UNFCCC, CAPRI calculates by 21% lower total emissions (378 Mt $CO_{2\text{-eq}}$ vs. 477 Mt $CO_{2\text{-eq}}$ for the emission categories of IPCC sector ‘agriculture’). The difference is mainly due to lower N_2O emissions following leaching of nitrogen (-55 Mt $CO_{2\text{-eq}}$) and CH_4 emissions from manure management (-23 Mt $CO_{2\text{-eq}}$). Differences are due to (i) different nitrogen excretion rates, which are endogenously calculated in CAPRI; (ii) the use of a mass-flow approach (MITERA model) for reactive nitrogen fluxes from manure; (iii) the use of IPCC 2006 instead of IPCC 1997 guidelines and other differences in parameters and factors applied; and finally (iv) the consideration of NH_3 reduction measures not considered in the IPCC methodology.

à The LCA methodology reveals that the IPCC sector ‘agriculture’ estimates only 57% of total GHG emissions caused by EU-27 livestock production up to the farm gate, including land use and land use change emissions. Accounting for the emissions from land use change, but not for land use emissions, this value is 67% (range 50%-72%).

à Emissions per kilogram of carcass of meat from ruminants cause highest GHG emissions (22 kg $CO_{2\text{-eq}}$/kg meat for beef and 20 kg $CO_{2\text{-eq}}$/kg sheep and goat meat). Pork and poultry meat have a lower carbon footprint with 7.5 $CO_{2\text{-eq}}$/kg meat and 5 kg $CO_{2\text{-eq}}$/kg meat, respectively. Eggs and milk from sheep and goat cause about 3 kg $CO_{2\text{-eq}}$/kg product, while cow milk has the lowest carbon footprint with 1.4 kg $CO_{2\text{-eq}}$/kg.

à The countries with the lowest product emissions are not necessarily characterized by similar production systems. So, the countries with the lowest emissions per kg of beef (Scenario II) are as diverse as Austria (14.2 kg $CO_{2\text{-eq}}$/kg) and the Netherlands (17.4 kg $CO_{2\text{-eq}}$/kg). While the Netherlands save emissions especially with low methane and N_2O rates indicating an efficient and industrialized production structure with strict environmental regulations, Austria outbalances the higher methane emissions by lower emissions from land use and land use change (LULUC) indicating high self-sufficiency in feed production and a high share of grass in the diet. The selection of the land use change scenario, therefore, impacts strongly on the relative performance (in scenario III the Netherlands fall back to average). However, both countries are characterized by high meat yields.

à Emissions from major imported animal products were calculated with a different methodology, and are, therefore, not directly comparable with other results of the study. Emissions of 33 kg $CO_{2\text{-eq}}$/kg are estimated for sheep meat from New Zealand, 80 or 48 kg $CO_{2\text{-eq}}$/kg for beef from Brazil, considering or neglecting emissions from land use change, respectively, and 1.2 kg $CO_{2\text{-eq}}$l/kg for chicken from Brazil. However, the estimate of land use change (LUC) related emissions is highly uncertain and must be used with extreme caution. The reason for the high GHG emissions from Brazilian beef – even without considering LUC emissions –is the low productivity of Brazilian beef compared with sheep in New Zealand causing both longer turn-over times and also lower digestibility of the feed and thus higher CH_4 emissions.

à Technological emission reduction measures might be able to reduce emissions from livestock production systems by 15-19%. Data for emission reductions are available mainly for NH_3 emissions, and are associated with high uncertainty; these measures often lead to an increase of GHG emissions, for example through the pollution swapping (manure management and manure application measures), or by increased emissions for fertilizer manufacturing (urea substitution). A reduced grazing intensity has complex and manifold effects which not all could be covered within this study. The results obtained indicate a small increase of emissions through lower digestibility of the feed. Only anaerobic digestion – in our simulation – shows positive effects with a reduction of GHG-emissions by ca. 60 Mt $CO_{2\text{-eq}}$.

à For the prospective analysis of the EU livestock sector, the reference scenario did not consider explicit policy measures for GHG emission abatement, but the scenario projection shows a trend driven reduction in GHG emissions for EU-27 of -6.8% in $CO_{2\text{-eq}}$ in the year 2020 compared to the reference year 2004. The four defined GHG emission abatement policy scenarios could be designed to almost achieve the reduction goal of 20% emission reduction compared to the reference year. The emission reduction effects per country in each scenario are quite different from the EU-27 average, depending on the production level and the composition of the agricultural activities. In all policy scenarios the largest decreases in agricultural activities are projected to take place at beef meat activities. The modelling exercise reveals that including emission leakage in the calculation diminishes the effective emission reduction commitment in the EU due to a shift of emissions from the EU to the rest of the world (mainly as a result of higher net imports of feed and animal products).

à The intensification of agriculture in the second half of the 20th century has contributed to biodiversity decline and loss throughout Europe, major factors being pollution and habitat fragmentation and loss. Major impacts from animal production are linked to excess of reactive nitrogen. On the other hand, many habitats important for biodiversity conservation are inherently linked to livestock production. Grazing is critical for maintaining many of Europe's cultural landscapes and sustaining rural communities.

The GGELS project calculated, for the first time, detailed product-based emissions of main livestock products (meat, milk and eggs) according to a cradle-to-gate life-cycle assessment at regional detail for the whole EU-27. Total emissions of European livestock production amount to 9.1% of total GHG emissions estimated in the national GHG inventories (EEA, 2010) or 12.8% if land use and land use change emissions are included. This number is lower than the value estimated in the FAO report 'livestock's long shadow' (FAO, 2006) of 18%, but for this comparison it has to be kept in mind that (i) GGELS estimates are only related to the EU, FAO results to the whole world, (ii) CAPRI estimates generally by 21% lower GHG emissions from agricultural activities, (iii) no other sector in this comparison is estimated on a product basis, and (iv) post-farm gate emissions are not considered in GGELS. Uncertainties are high and could not be quantified in the present study. In particular, good data for the quantification of land use and land use change emissions are lacking, but there is also high uncertainty around emission factors and farm production methods such as the share of manure management systems.

1. ACRONYMS

AA	Administrative Arrangement
AGRI-ENV	Agriculture and Environment action of the Rural, Water and Ecosystem Resources unit, Institute of environment and sustainability, JRC
AGRITRADE	Support to Agricultural Trade and Market Policies action of the Agriculture and Life Sciences in the Economy unit, Institute for Prospective Technological Studies, JRC
AWMS	Animal Waste Management System
CAC	Command and control
CAPRI	Common Agricultural Policy Regional Impact (partial equilibrium model)
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
COPA-COGECA	Union of European farmers and agri-cooperatives
EAA	Economic Accounts on Agriculture: Eurostat database
EDGAR	Emission Database for Global Atmospheric Research
ETS	Emission trading system
EU	European Union, 27 member states
EU-12	12 EU Member States of 2004 and 2007 enlargements
EU-15	15 EU Member States before the 2004 enlargement
EU-27	27 EU Member States after the 2007 enlargement
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization of the United Nations
GeoCAP	Geo-information for the Common Agricultural Policy action of the Agriculture unit, Institute for the Protection and Security of the Citizen, JRC
GGELS	Project acronym “Greenhouse Gas from the European Livestock Sector” of the JRC project “Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions”
GHG	Greenhouse Gas
GHG-AFOLU	GHG emissions from Agriculture, Forestry and Land Use action of the Climate Change unit, Institute of environment and sustainability, JRC
ICPA	Integrated Climate Policy Assessment action of the Climate Change unit, Institute of environment and sustainability, JRC
IE	Institut de l’Élevage: French livestock board

IES	Institute for Environment and Sustainability of the EC-Joint Research Centre
IPCC	Intergovernmental Panel on Climate Change
IPSC	Institute for the Protection and Security of the Citizen of the EC-Joint Research Centre
IPTS	Institute for Prospective Technological Studies of the EC-Joint Research Centre
JI	Joint Implementation
JRC	Joint Research Centre
KP	Kyoto Protocol
LCA	Life Cycle Analysis
LPS	European Livestock Production System
MAC	Marginal Abatement Cost
MS	Member State(s)
NUTS	Nomenclature of Territorial Units for Statistics
NUTS	Nomenclature of Territorial Units for Statistics; harmonized EU administrative region denomination
REF	Reference scenario (baseline)
UNFCCC	United Nations Framework Convention on Climate Change