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

- Final report -

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

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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.

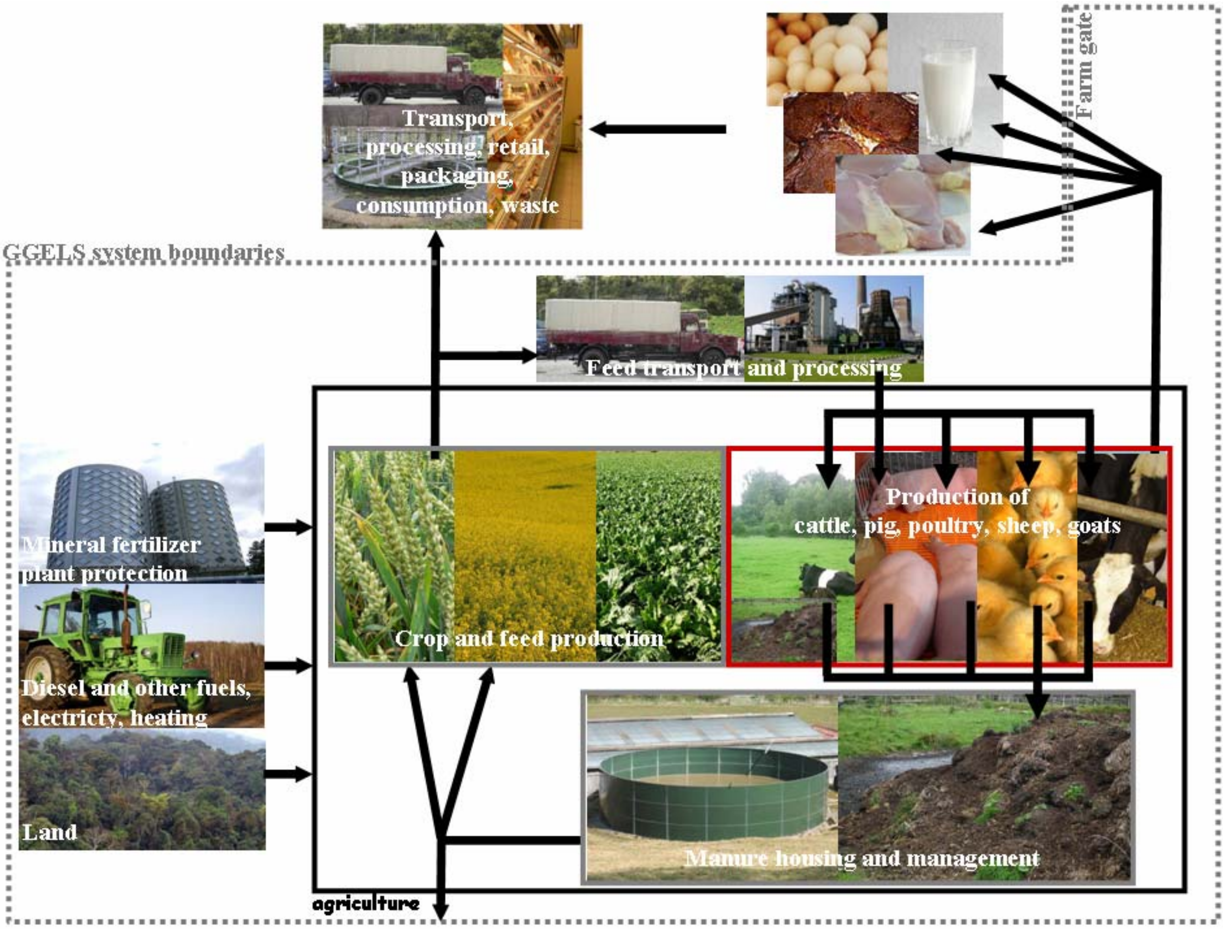

Figure ES1. System boundaries for the GGELS project.

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.

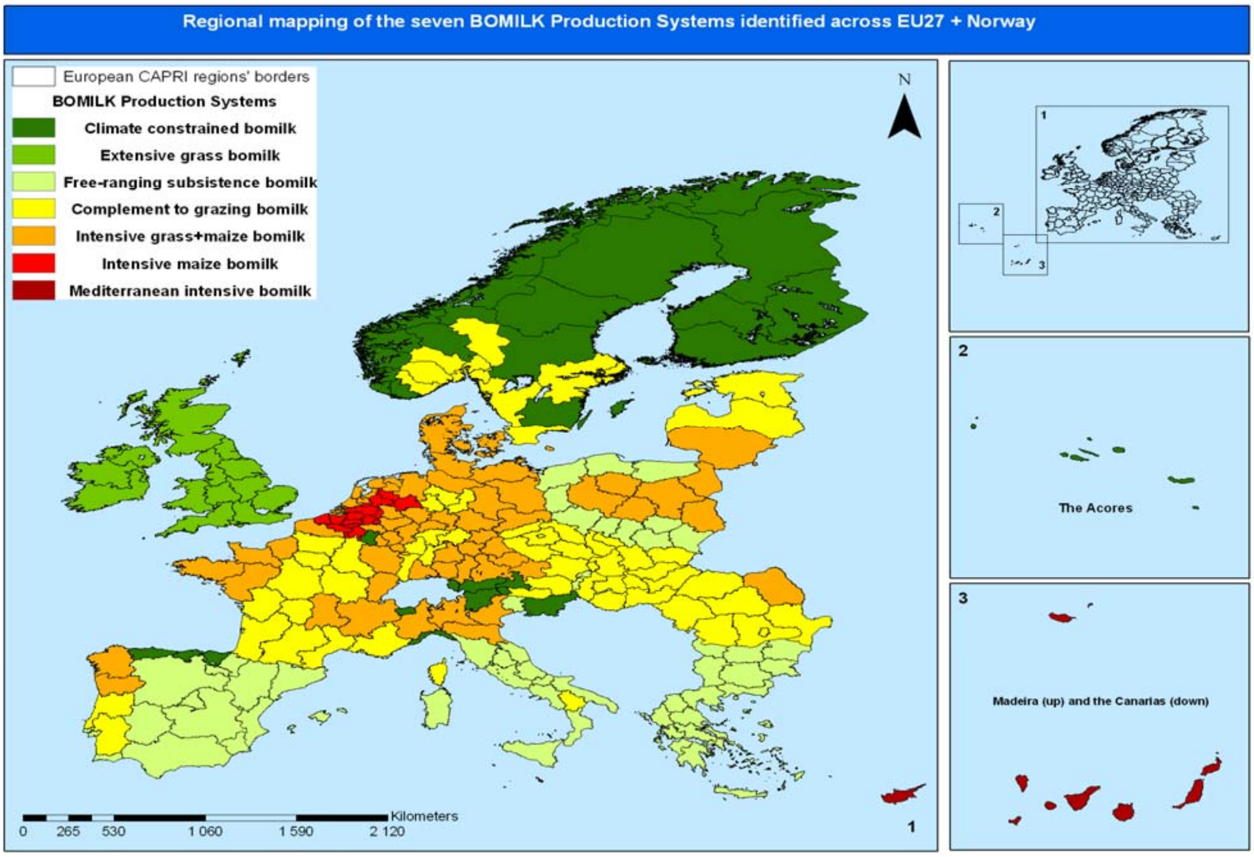

Figure ES2: Diversity of the BOMILK Production Systems in EU-27 + Norway

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.

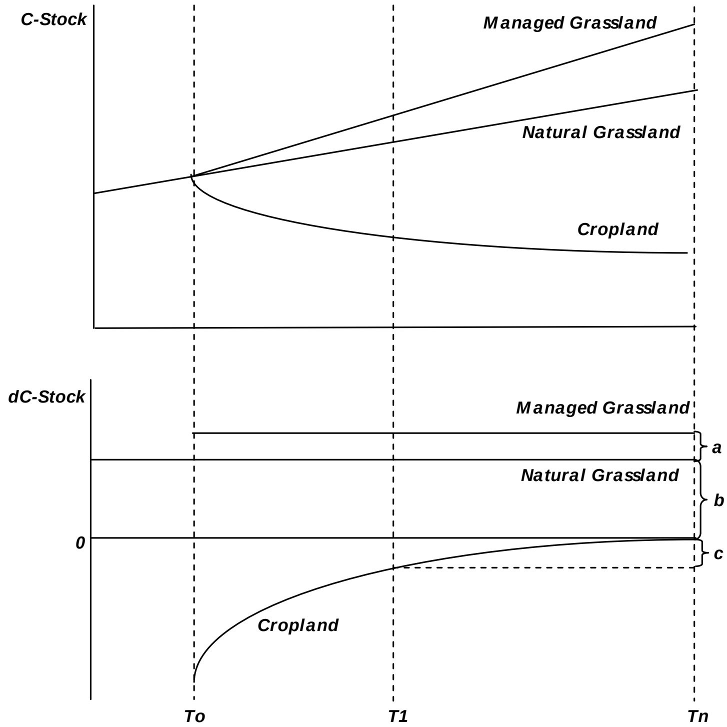

Figure ES3. Schematic illustration of the implementation of carbon sequestration in CAPRI. At time t1 natural grassland is converted to either managed grassland or cropland. The carbon sequestration rate of the land use increases for the grassland (a), but drops to zero (b) for the cropland. This is 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.

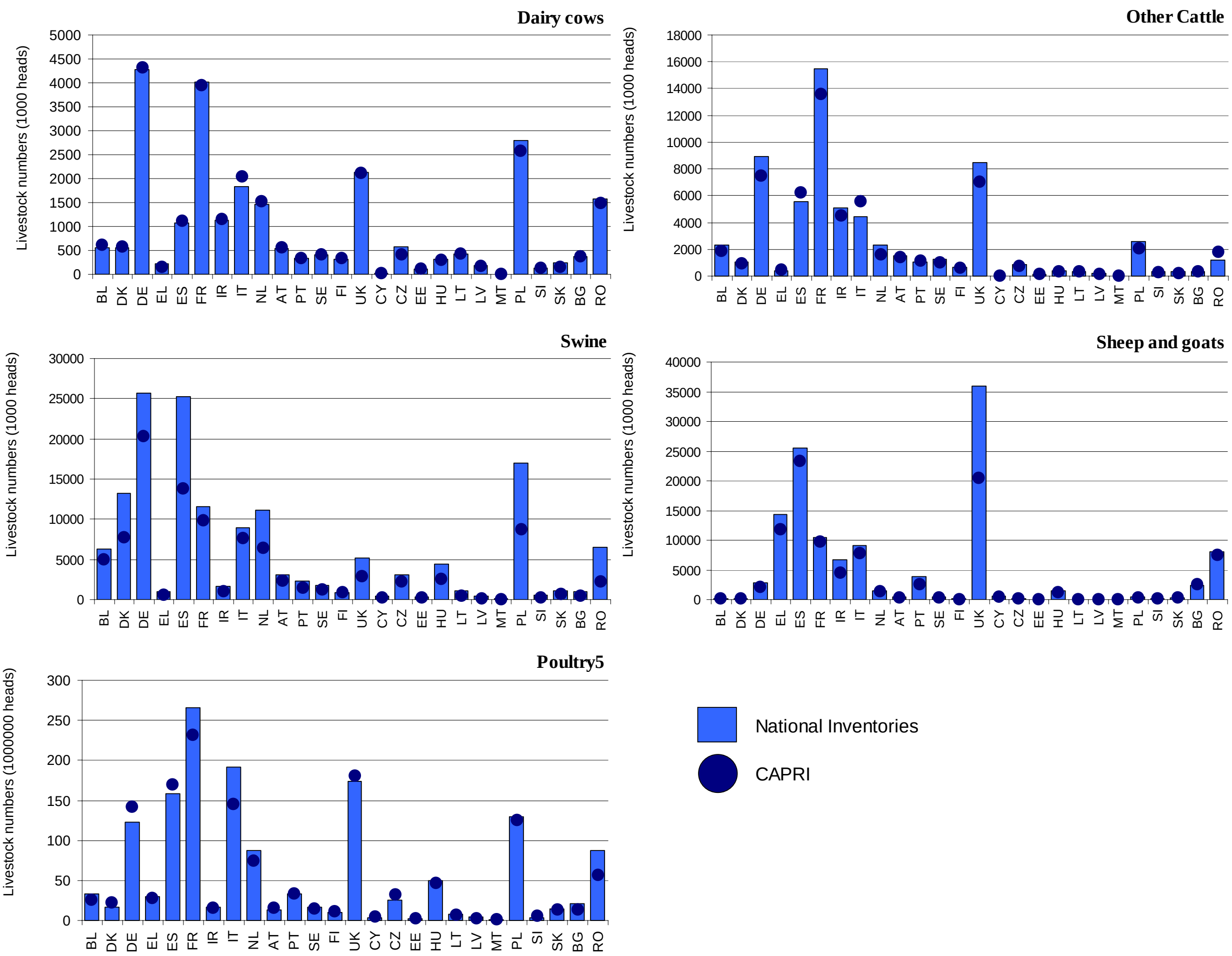

Figure ES4. Comparison of livestock numbers used in National Inventories to the UNFCCC for the year 2004 (EEA, 2010) and livestock numbers used in CAPRI

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.

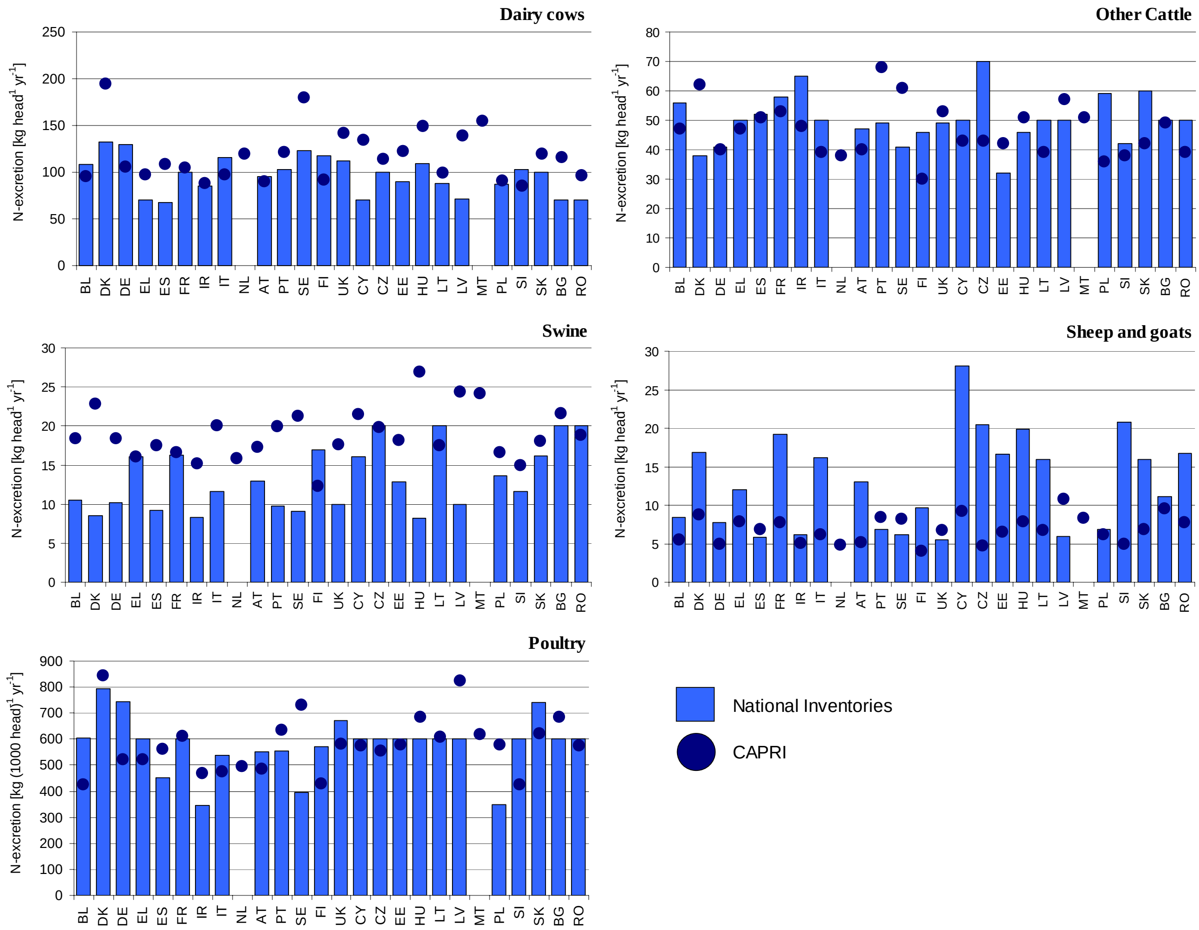

Figure ES5. Comparison of N-excretion data used in National Inventories to the UNFCCC for the year 2004 (EEA, 2010) and N-excretion data calculated with CAPRI

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.

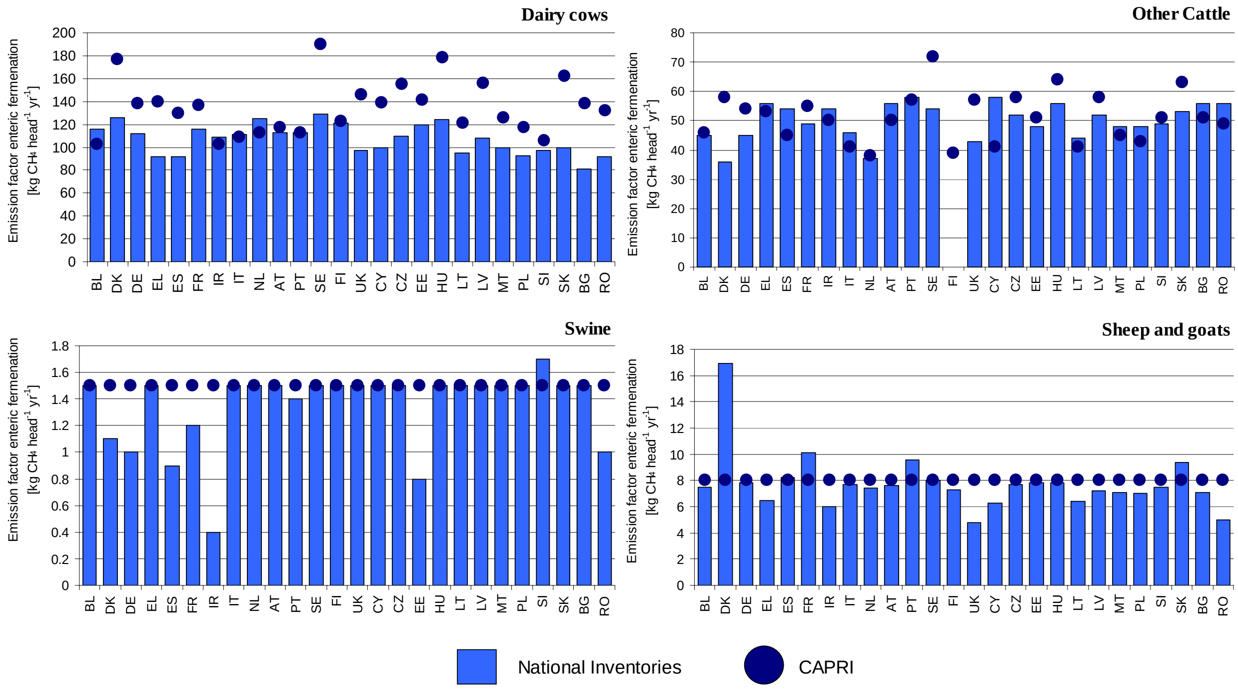

Figure ES6. Comparison of emission factors for enteric fermentation in dairy and non-dairy cattle, swine, and sheep and goats used in National Inventories to the UNFCCC for the year 2004 (EEA, 2010) and the emission factors calculated (in case of dairy and non-dairy cattle) or used (in case of swine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

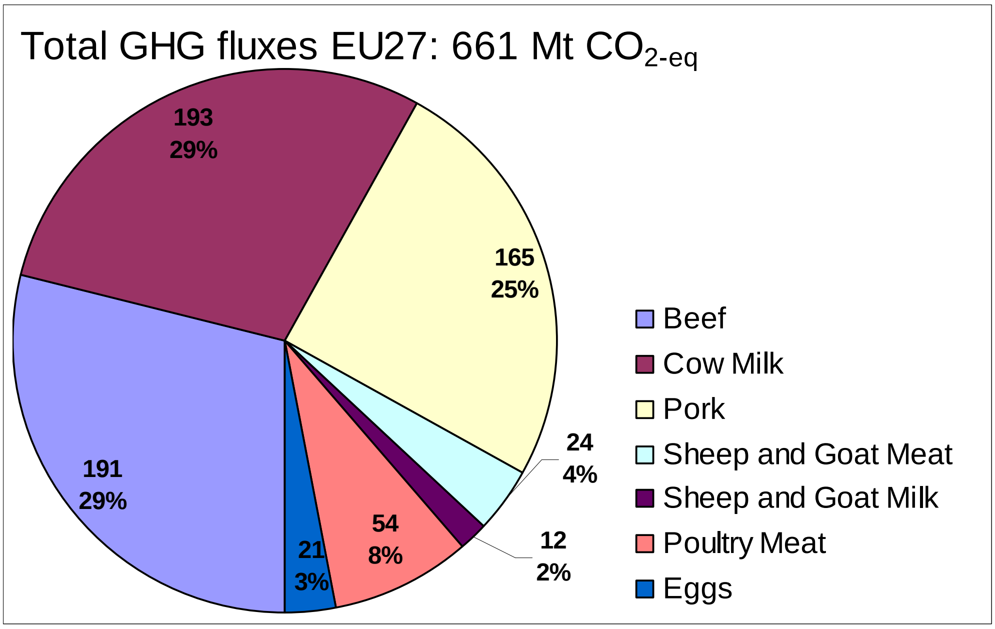

Figure ES7. Total GHG fluxes of EU-27 livestock production in 2004, calculated with a cradle-to-gate life-cycle analysis with CAPRI

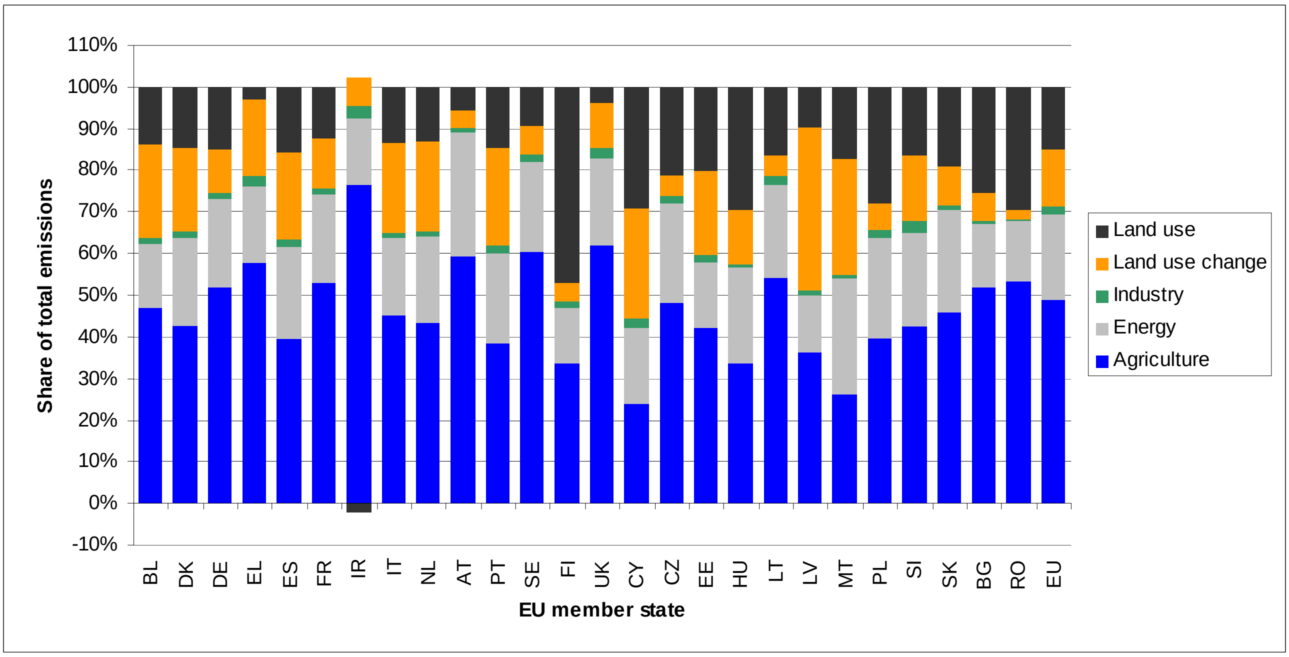

Figure ES8. Share of different sectors on total GHG emissions. In this graph, the land use and the land-use change sector are depicted separately.

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%.

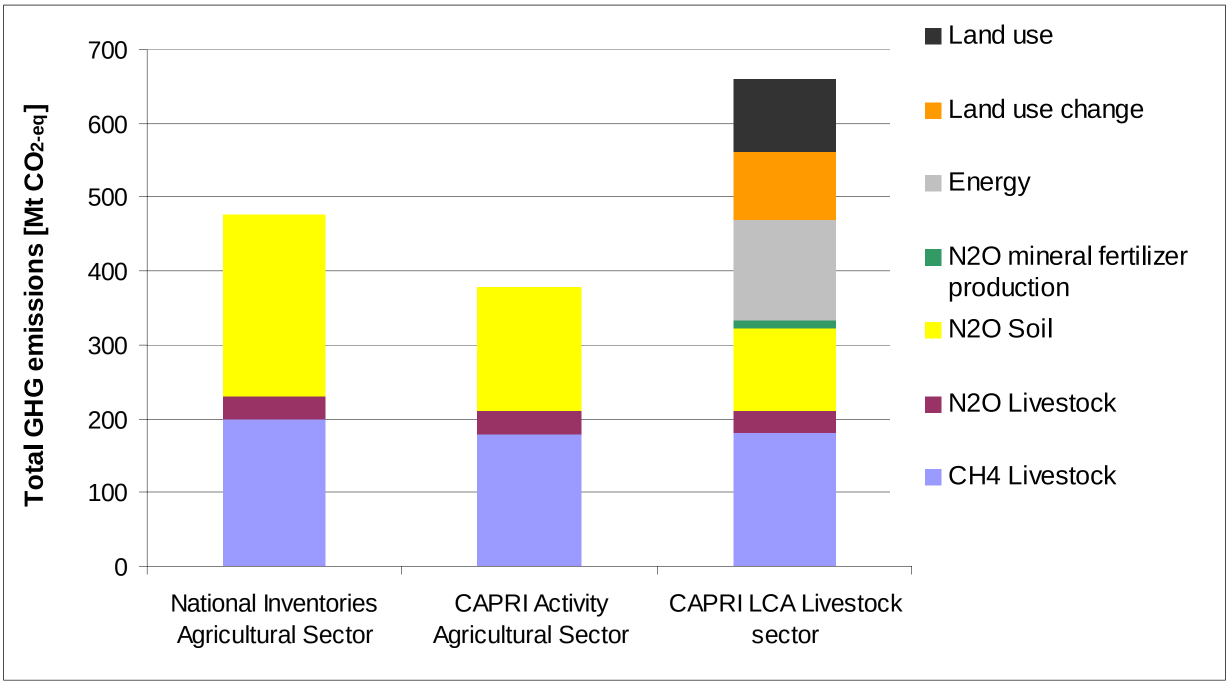

Figure ES9. Total GHG fluxes of EU-27 in 2004 of the agriculture sector as submitted by the national GHG inventories to the UNFCCC (left column, EEA, 2010), calculated with CARPI for the IPCC sector agriculture with the CAPRI model (middle column), and calculated with a cradle-to-gate life-cycle analysis 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.

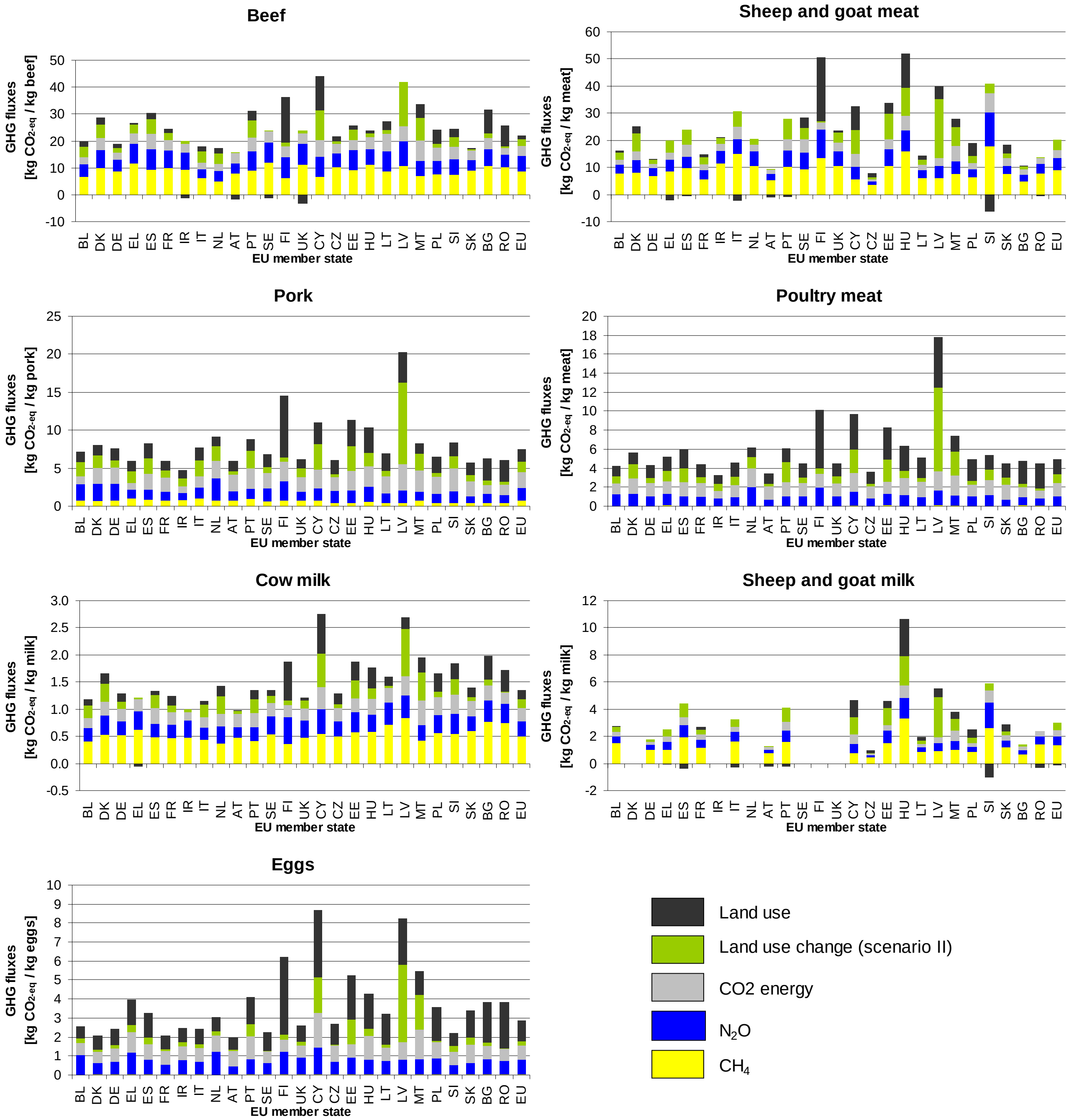

Figure ES10. Total GHG fluxes of EU-27 livestock products in 2004, calculated with a cradle-to-gate life-cycle analysis with CAPRI

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-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).

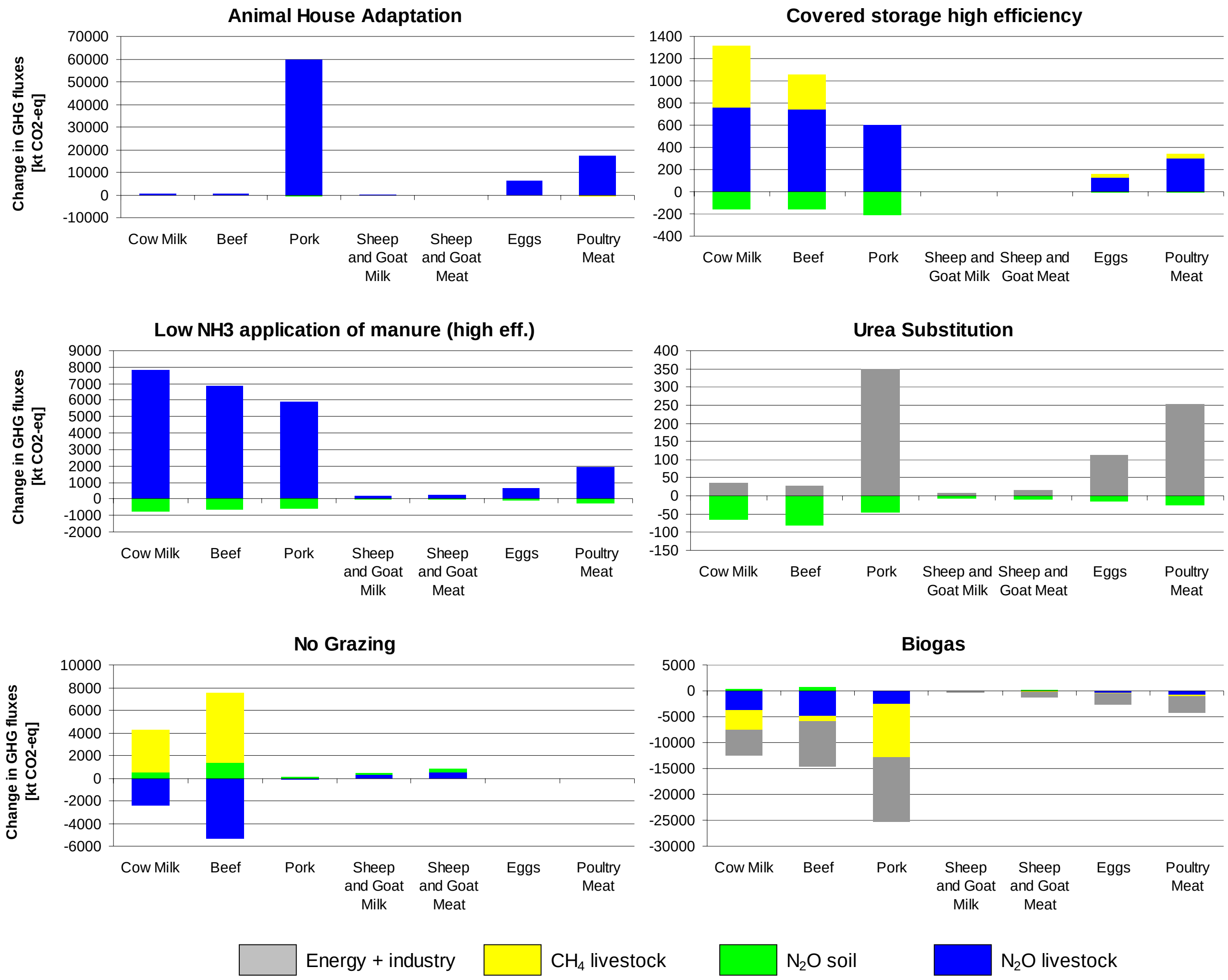

Figure ES11. Impact of selected technological abatement measures, compared with the reference situation for the year 2004, if the measure would be applied by all farms, calculated with a cradle-to-gate life-cycle analysis with CAPRI

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-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-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-eq} per kilogram of meat varies between 1.2 kg CO_{2-eq}/kg meat for chicken from brazil over 33 kg CO_{2-eq}/kg meat for sheep meat from New Zealand to 80 kg CO_{2-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-eq} much lower than emissions from imported sheep meat from New Zealand (6.4 Mt CO_{2-eq}) or beef meat from Brazil (8.7 Mt CO_{2-eq} or 14.4 Mt CO_{2-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.

→ 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-eq} and 283 Mt CO_{2-eq}

→ Compared with official GHG inventories submitted to the UNFCCC, CAPRI calculates by 21% lower total emissions (378 Mt CO_{2-eq} vs. 477 Mt CO_{2-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-eq}) and CH_4 emissions from manure management (-23 Mt CO_{2-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.

→ 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%).

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

→ 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-eq}/kg) and the Netherlands (17.4 kg CO_{2-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.

→ 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-eq}/kg are estimated for sheep meat from New Zealand, 80 or 48 kg CO_{2-eq}/kg for beef from Brazil, considering or neglecting emissions from land use change, respectively, and 1.2 kg CO_{2-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.

→ 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 $CO_{2\text{-eq}}$.

→ 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).

→ 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. INTRODUCTION

The contribution of the livestock sector to climate change has been on the front page of different media since the FAO (2006) published its report: "*Livestock long shadow: environmental issues and options*" at the end of 2006.

The FAO report claims that livestock production is a major contributor to the world's environmental problems, including climate change. At global level, the report estimates that livestock accounts for a significant share of greenhouse gas (GHG) emissions (about 18% of total anthropogenic 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 methodology used considers GHG emissions (CO_2, CH_4 and N_2O) and ammonia throughout the whole food chain, from land use changes for the production of animal feed to transport and processing of animal products. Nevertheless, the spotlight is on emissions generated at farm level, as the gases emitted in the subsequent part of the commodity chain are estimated to be relatively low. Other recent papers following a life cycle approach have also pointed out the significant role of livestock in the emissions of GHG (Casey and Holden, 2005; Galloway et al., 2010; Garnett, 2009; Stehfest et al., 2009; Steinfeld and Wassenaar, 2007).

The forth Assessment Report of the Intergovernmental Panel on Climate Change (AR4, IPCC) gives the largest and most detailed summary of current scientific understanding of climate change to date. According to AR4, world global GHG emissions reached roughly 50 Gt $CO_{2\text{-eq}}$ yr^{-1} in 2007. Agriculture was responsible for 10% of GHG emissions, or 5-6 Gt $CO_{2\text{-eq}}$ yr^{-1}.Only about 5% of total emissions from agriculture accounted for are direct CO_2 gas. The remainder is roughly equally split between CH_4 and N_2O. More specifically, according to the AR4, about 40% of global agricultural emissions are from soil N_2O (2.3 Gt $CO_{2\text{-eq}}$ yr^{-1}); one-third from livestock enteric fermentation (1.9 Gt $CO_{2\text{-eq}}$ yr^{-1}); 12% from rice cultivation (700 Mt $CO_{2\text{-eq}}$ yr^{-1}); and only 7% from manure management—including storage and disposal (420 Mt $CO_{2\text{-eq}}$ yr^{-1}). Over two-thirds of global agricultural GHG emissions are located in developing countries.

GHG emissions in the EU are annually compiled by the European Commission and submitted to the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) for the whole time series since the base year (usually 1990) and the most current year for which estimates exist (for the latest submission this was the year 2008). In 2008, 4940 Tg $CO_{2\text{-eq}}$ (without LULUCF) were emitted, while the land use, land use change and forestry (LULUCF) sector was a sink for 410 Tg $CO_{2\text{-eq}}$ (EEA, 2010). Agriculture, according to the report from EEA contributed with 472 Tg $CO_{2\text{-eq}}$ (9.6%), a somewhat higher estimate than presented in the inventory of the previous year (462 Tg $CO_{2\text{-eq}}$, EEA 2009). Indeed, the agricultural sector was the second largest GHG emitter among activity sectors—second only to energy and greater than emissions from industry (EU-EEA, 2009). Compared to the base year, total emissions went down by 11.3% (not considering LULUCF). Reductions in the agriculture sector (-20.3%) were above average, most of them being observed in the central-eastern countries.

Both direct and indirect GHG emissions related to the livestock sector contribute to this global and regional picture (IPCC, 2007a; FAO 2006). Directly, livestock rearing and management is responsible for biogenic emissions of CH_4 through enteric fermentation, mostly in cattle; as well as from livestock manure – whether within the boundaries of livestock stables and farm compounds, or

applied to cropland and grasslands. At the same time, animal waste management systems directly emit very significant amounts of N_2O. Indirectly, livestock is responsible for the portion of agricultural GHG emissions related to crop cultivation that is used to feed the animals, including soil emissions from the application of mineral fertilizers, crop residues or the cultivation of organic soils, industrial emissions from the production of mineral fertilizers and emissions from land use and land use change. Finally, crop and livestock production are both related to the consumption of energy, on the farm as well as for production of farm-inputs and transport of goods.

Grazing livestock, in particular extensive rearing systems, was particularly identified in the FAO report as having the most negative effect from the climate change perspective, due to its land area needs, its low productivity, and the inherent methane emissions from ruminant digestion. In the EU, grazing livestock systems differ strongly from that of other world regions, in terms of land use and related dynamics, feeding patterns, and productivity. Therefore, the results of the FAO global analysis cannot be directly transposed to the EU.

The food chain approach followed by the FAO is different from the internationally agreed methodology of GHG emissions accounting within the UNFCCC, co-ordinated by the IPCC. For example, according to the IPCC methodology, emissions of CO_2 from the energy use of agricultural machinery and farm operations, are not accounted in the ‘agriculture’ sector but are included in the ‘energy’ sector; emissions generated by the land use changes linked to livestock activities are not accounted under the ‘agriculture’ category, but instead are reported under the ‘Land use, land use changes and forestry’.

By attributing emissions to the activity generating them, the IPCC approach shares responsibility between these activities. However, since these activities most often produce intermediate products which are part of a long and complex chain of production processes, many other activities bearing an indirect responsibility are not visible (in particular the end product consumed and to which all activities are dedicated). The entire food/production chain of (animal) products brings such contributions to light.

This study “***Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions***” (GGELS) was commissioned by the Directorate-General for Agriculture and Rural Development in order go get an estimation of the net emissions of greenhouse gases generated by EU-27 animal production, as the official agricultural inventory (and its categories) does not allow for such detailed analysis. The study also intends to help DG AGRI to respond to the growing political and social concern about livestock's contribution to climate change within the EU, as well as to support other analytical work as the undergoing CAP reform or any future work in the field of livestock emissions.

DG AGRI also requested to consider other impacts of livestock, particularly regarding conservation of habitats and biodiversity, in order to have a broader picture of the overall livestock's implications for the environment. This will be useful to improve Commission understanding of potential synergies and trade-offs between different policy objectives, such as climate change and biodiversity protection.

Finally, the main role of DG AGRI during the project was to coordinate the liaison between the JRC and the steering group created for the study and organize several meetings during the two phases of the project.

The present report is the final report of the GGELS study, gathering all information and model results compiled during the course of the project.

1.1. The GGELS project

The objective of the GGELS project was to provide an estimate of the net emissions of greenhouse gases and ammonia from livestock sector in the EU-27 according to animal species, animal products and livestock systems. The work followed an EU-27 production chain perspective and focused on the emissions generated from livestock production considering all emissions upstream of the farm (‘cradle’) to the farm gate. Emissions from off-farm transport (of animals or products), processing and refrigeration of animal products were not covered. Several studies have already addressed the emissions from these downstream phases of the livestock chain, which are generally considered as less significant emitters than the upstream phases (FAO, 2006; FAO, 2010; IDF, 2009).

The main scope of the GGELS project is given below.

1.1.1. System boundaries

The system boundaries of this project are schematically shown in Figure 1.1. Considered are all on-farm emissions including emissions caused by providing input of mineral fertilizers, pesticides, energy, and land. 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.

1.1.2. Emission sources

Specifically, the emissions considered include (i) on-farm livestock rearing including emissions from 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, emissions from the cultivation of organic soils, emissions from crop residues and related upstream industrial processes (fertilizer production); (iii) emissions related to on-farm energy consumption and energy consumption for the transport and processing of feed; (iv) emissions (or removals) related to land use changes induced by livestock activities (feed production excluding grassland); and (v) emissions (or removals) from land use through changes in carbon sequestration rates (feed production including grassland).

1.1.3. Environmental indicators

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 1.1. Table 1.1 indicates also whether the emissions are caused directly by livestock rearing activities or cropping activities for the production of feed.

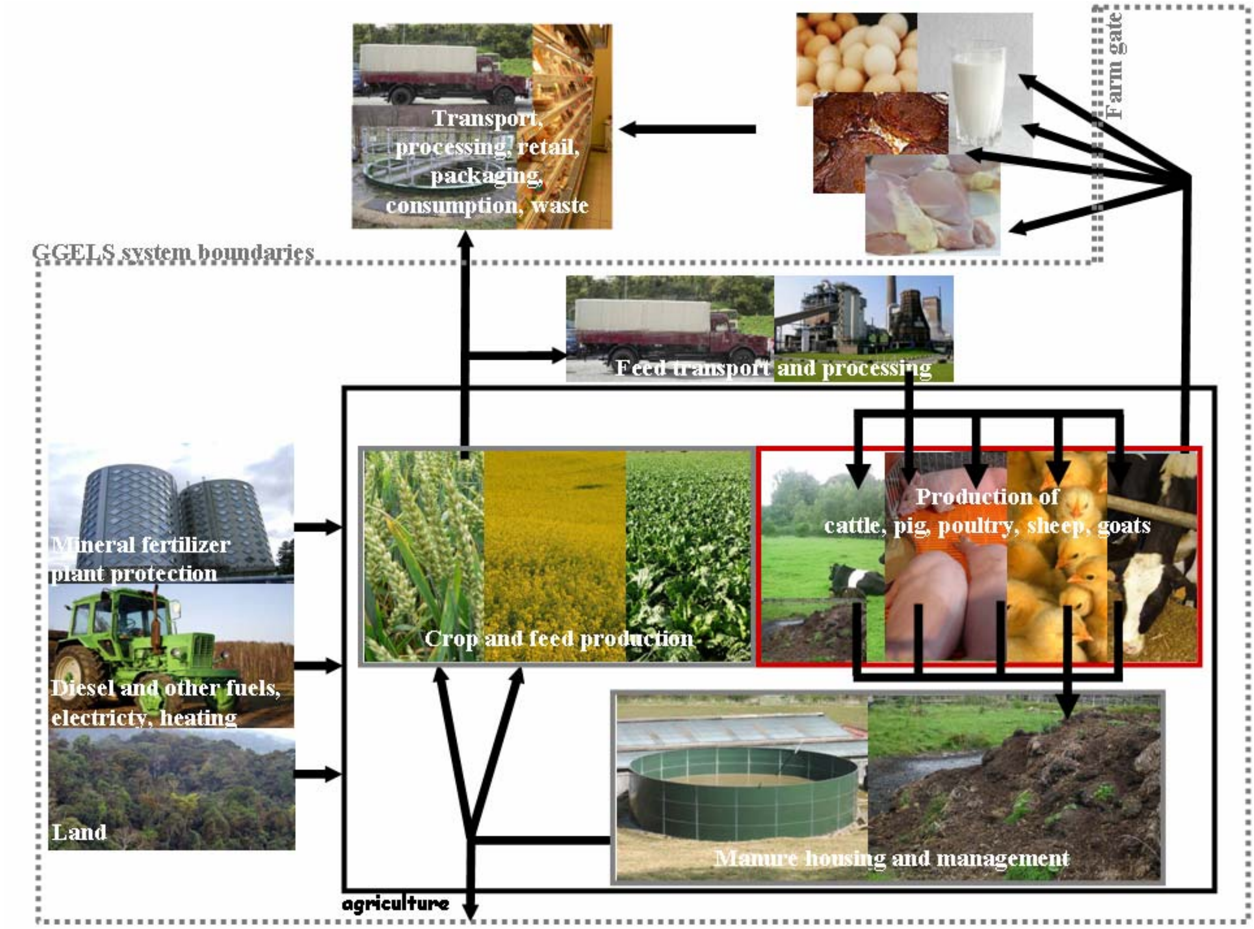

Figure 1.1. System boundaries for the GGELS project.

1.1.4. Functional unit

The study covers the main food productive animal species:

- → beef cattle
- → dairy cattle
- → small ruminants (sheep and goats)
- → pigs
- → 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.

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 eggs including the shell.

Table 1.1. 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

1.1.5. Allocation

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. Allocation of manure applied on crops that are not used as feed is avoided by system expansion. Avoided emissions through substitution of the application of mineral fertilizer are credited by the emissions that would have been caused if mineral fertilizer would have been applied instead.

1.1.6. Geographic scope and time frame

Emissions from livestock production are estimated for EU-27 Member States. Emissions from feed consumed by animals in the EU-27 are estimated regardless their origin. The spatial detail of the study is at the level of NUTS 2 regions.

Even though the study focuses on estimating the current absolute amount of GHG emissions, it will also give an indication of possible future emission trends. The time frame thus includes: (i) current emissions (year 2004); (ii) emission trends on the basis of existing economic projections (year 2020 baseline of the CAPRI model).

1.1.7. Limitations

It is important to draw the boundaries of the scope of the project precisely, as some important aspects are out of the scope of the project defined above, had to be ignored or could not be assessed with the available methodologies. In particular:

- **GGELS assesses emissions related to animal production and not emissions related to the consumption of animal products**. Thus this report does not deal with questions such as what impact a diet of European citizen with less or no red meat on the environment has. Also, the emissions related to transport, cooling and further processing of animal products have not been included in the present study. For example, the consequences of a diet-change would be manifold and complex. A reduction of red-meat consumption could curb the size of the animal herds with the effect of reduced direct GHG emissions from the animals (e.g. CH_4 emissions from enteric fermentation and N_2O emissions from manure management) and it would also reduce the need to grow or import feed crops. On the other hand, the protein demand would be satisfied by other products with associated emissions, the response of the market could lead to emission leakages and so on. Thus, with the tools at hand, it is not possible to quantify the effect of changing consumer's behaviour – as it also was not foreseen to be included in the GGELS project. Nevertheless, with regard to the impact of the wide range of animal products from global world regions on GHG and NH_3 emissions, chapter 9.2 analyses on the basis of literature data the emissions of the most important animal products that are imported into the European Union: meat of sheep and goat from New Zealand and beef and poultry meat imported from Brazil.
- **GGELS cannot give quantitative estimations of technically and economically feasible abatement potentials.** Reduction of the emissions of greenhouse gases and ammonia from agricultural sources is an important topic and might help reaching national emission reduction targets. The assessment of technically and economically feasible emission reduction potentials is challenging and requires (i) robust technical emission reduction factors for mitigation measures; (ii) the cost of technical and policy mitigation measures including technical and socio-economic barriers preventing their implementations; (iii) and a thorough assessment of feed-backs and (undesired) side effects, including pollution swapping, consumer behavioural changes, etc. In GGELS, a review of technological emission reduction factors for European conditions has been made in chapter 7.2. The technological potential has been assessed with the LCA-model in chapter 7.3. Due to the lack of current implementation rates, this assessment quantifies the impact this measure

would have if implemented by all farms, compared to the reference situation. Selected policy mitigation options are examined in chapter 8. Again, due to the lack of appropriate data this assessment must be seen as exploratory.

- **GGELS assesses the impact of EU-livestock production on GHG and NH_3 emission levels, but cannot give a comprehensive overview of the environmental impact of EU-livestock production.** Agriculture has many interactions 'with the environment'. Emissions of radiative active gases (CH_4, N_2O, CO_2) or emissions of substances that are precursors of radiative active gases (NH_3, NO_x, nitrate) have been quantified in the present study and reported as $CO_{2\text{-eq}}$. NH_3 as the most important precursor of indirect N_2O emissions and also the most important air pollutant emitted by agriculture is explicitly included in the report as well. Emissions of nitrate are quantified to estimate indirect N_2O emissions, but are not analysed in depth for their effect on ground and surface water pollution. Other pollutants of Europe's hydrosphere such as pesticides, or soil pollutants, such as heavy metals, are not covered by the GGELS project. Also, effects of livestock production systems on soil quality (erosion, compaction, etc.) could not be considered. As one of the most important impacts of agriculture on the environment next to their contribution to the emissions of GHGs and air pollutants, however, we have included an overview of the impact of the livestock sector on EU biodiversity at the present situation (chapter 9.1).

- **In the frame of GGELS no in-depth assessment of the uncertainty of the model results or their sensitivity with respect to uncertain input data could be done.** This would require to go through all data estimating distribution/uncertainty of each of them and to carry out stochastic simulations and is thus only possible in a separate project. Thus the values presented have to be interpreted as 'best available estimates', obtained with the use of state-of-the-art modelling approaches and carefully compiled input data. Nevertheless, the report points already to large gaps in high-quality input data, for example with respect to information on farm management, which could not be closed despite considerable effort undertaken with an expert-questionnaire. Also the comparison of GGELS results with official national GHG inventory data highlights large discrepancies in the data as a consequence of differences in approaches, input data, and factors used. A dedicated analysis of the uncertainty of each of these items and their sensitivity to model results would be highly desirable.

1.2. Structure of this report

While chapter 2 provides a short overview of the livestock sector in Europe, a detailed typology of livestock production systems in Europe is developed in chapter 3. This typology is also used to provide a systematic presentation of the results of the LCA-analysis for bovine meat and milk products. The LCA methodology is described in detail in chapter 4. The first part of this chapter explains the calculations required to estimate emissions directly created by agricultural activities (per head of animal or hectare of feed grown), while the second part of chapter 4 adds the steps required for the life-cycle approach. Results of the activity-based calculations are presented in chapter 5 and compared with the data obtained from national greenhouse gas inventories submitted to the UNFCCC. The product-based results obtained by the LCA-calculation are then presented in chapter 6.

Chapter 7 is dedicated to exploring technological abatement measures. A prospective analysis is given in chapter 8, estimating emissions for a reference situation in 2020 and selected policy options for mitigating GHG emissions.

Chapter 9 finally completes the report with ancillary assessments which have been carried out independently of the methodologies developed in GGELS, but address important aspects: the impact of present livestock systems on biodiversity and the GHG emissions associated with imported animal products.

Conclusions are drawn in chapter 10.

2. OVERVIEW OF THE EU LIVESTOCK SECTOR

Authors: Tom Wassenaar and Suvi Monni

This chapter aims to provide insight into the European livestock sector at a broad level, describing its importance from various perspectives at EU and member state (MS) level. Many recent reports and articles, particularly those addressing environmental impacts, refer to the abstract notion of "the livestock sector", and GGELS is not an exception. Readers' interpretation of these works is often influenced by the subjective image one attaches to this abstract notion. A European citizen is for example likely to think of a Holstein dairy cow reared on lush pasture without knowing the representativeness of this image. Regarding the sensitivity of politics and the public opinion at large to livestock-environment issues, it is important to promote objectivity by informing about the wide range of species and production systems that make up this complex sector, and their relative importance.

2.1. The importance of livestock production in the EU and its MS

2.1.1. Economic importance

In 2007 livestock production accounted for 41% of agricultural output in value terms, representing 1.2% of the European Union's GDP. Highest GDP shares are found in "new" member states (with Bulgaria, 4.4%, and Romania, 3.8%, standing out), while lowest shares are found in Luxemburg (0.5%), United Kingdom (0.6%) and Sweden (0.7%). This does not reflect the dynamics of the relative importance of livestock production in agricultural output: Ranging from 28% of agricultural output in the case of Greece to 69% in the case of Ireland these extremes seem to be substantially influenced by bio-physical conditions.

In addition to the overall economic importance per country, Table 2.1 also shows the relative contribution of the main subsectors. At EU level the spread over the different output categories illustrates the diversified nature of the EU livestock sector. Still the dairy sector comes out as a relative heavyweight in economic terms: milk output is highest, to which has to be added the fact that about 60% of beef also originates from the dairy sector (CEAS 2000; Ernst&Young 2007), resulting in a total of some 45% of the livestock sector's output.

Output levels of milk, a fundamental while bulky and perishable food element, are understandably substantial in all MS (ranging from about 1/5 to well over half of livestock output). Output levels of other "farm gate" commodities vary more strongly, leading in a number of MS to a clearly specialized livestock economy at national level. These are readily identified in Table 2.1: "dairy-beef" in France and Ireland; "pig" in Spain and Denmark; "sheep and goat" in Greece and "pig-poultry" in Hungary.

Table 2.1: EU livestock sector's 2007 economic output (Eurostat 2008).

Member state	Livestock Production			Share (%) of livestock production (value terms)						
	Million euro	Agricultural output share	GDP share	Milk	Egg	Beef	Pig meat	Sheep and goat	Poultry meat	Other animal produce
fr	23542	36.4%	1.2%	31	4	34	12	3	13	3
de	20400	45.1%	0.8%	47	3	15	25	0	8	2
it	14441	33.5%	0.9%	30	7	23	16	2	15	8
es	14296	36.6%	1.4%	19	6	15	33	11	13	2
uk	12301	56.8%	0.6%	33	5	26	9	9	14	3
nl	9140	39.9%	1.6%	43	5	18	22	1	8	3
pl	8994	45.5%	2.9%	35	8	10	28	0	17	2
dk	5449	60.2%	2.4%	27	2	6	44	0	3	18
ro	4584	34.7%	3.8%	30	15	11	21	4	10	9
ie	4092	68.5%	2.1%	40	1	37	7	4	4	7
be	3799	52.0%	1.1%	25	3	27	34	0	9	1
at	2883	48.0%	1.1%	33	6	29	23	1	5	4
gr	2881	27.9%	1.3%	37	5	8	9	27	5	9
pt	2499	37.9%	1.5%	30	4	20	19	5	16	7
hu	2296	35.4%	2.3%	22	9	5	28	2	27	7
fi	2259	55.2%	1.3%	46	2	15	15	0	6	15
se	2225	47.7%	0.7%	44	5	18	16	1	5	10
cz	1763	41.6%	1.4%	43	4	16	23	0	13	0
bg	1259	41.4%	4.4%	39	9	9	13	13	14	4
sk	941	48.9%	1.7%	31	10	13	21	1	13	12
lt	892	45.7%	3.1%	51	6	16	16	0	9	1
si	572	50.6%	1.7%	32	4	29	18	2	14	3
lv	411	43.4%	2.1%	49	8	11	15	1	9	7
cy	305	50.9%	2.0%	28	4	4	28	11	21	4
ee	303	48.2%	2.0%	55	3	8	22	1	6	6
lu	165	60.7%	0.5%	57	2	30	10	0	0	0
mt	71	59.5%	1.3%	24	11	6	22	1	10	26
EU-27	142190	41.4%	1.2%	34	5	20	21	4	11	5

2.1.2. Production volumes

Even before the 2004 enlargement, the EU was already the world's largest dairy producer (120 million tons per year, 24% of which from Germany, 20% from France, 13% from the UK and 10% from the Netherlands). With the 2004 and 2007 enlargements the EU dairy cow herd rose from about 18 million heads to over 24 million heads.

The EU is the world's second largest producer of beef after the United States, with Brazil trailing only slightly in third place. The EU produces around 8 million tonnes of beef a year, predominantly in the EU-15 MS. Total number of cattle in the EU27 amounts to almost 90 million animals. France has by far the EU's largest cattle herd, with more than 19 million animals, followed by Germany (about 12.7 mio) and Britain (10.3 mio.). Italy, Ireland, Spain and Poland are each home to around 6 million cattle.

For pork, the EU is the world's second largest producer after China and turns out about 22 million tonnes annually. Again, the bulk comes from the EU-15 MS. Germany is the EU's largest pig rearer, with almost 25 million animals, followed by Spain, with 23 million.

The EU produces around 11 million tonnes of poultry meat and 1 million tonnes of sheep and goat meat a year. Britain leads in sheep with 24 million animals, closely followed by Spain. Greece has by far the most goats, with more than 40% of the EU total, again followed by Spain. Britain also has the most hatching chicks, followed by France. Germany, Spain and Poland are also big producers.

Pork accounts for 45% of the meat consumed in the EU, followed by poultry, at 25%, and beef/veal at 19%. Europeans consume around 43 kg a year of pork, 23 kg of poultry meat, 18 kg of beef and veal and only 3 kg of mutton and goat meat. These meat consumption percentages roughly reflect the sectoral split of output in volume terms, but constitute a marked contrast with the production output split in value terms presented in the preceding paragraph.

As demonstrated by the production figures in weight terms presented in Annex 1.1 to this chapter, production levels vary strongly among member states, a fact that is affecting relative livestock greenhouse gas emissions levels among EU MS. Differences in production levels are partly explained by differences in national consumption, influenced by population size and per capita consumption, the latter varying substantially in the case of meat. At least as important for explaining production level differences is the interdependence among MS as evidenced by the varying self sufficiency levels: a limited number of MS are important production centres that supply a large number of other MS with a share of their produce. Production exhibits substantial and similar concentration at EU level for all main commodities, with Germany, Spain, France and Italy standing out, followed by the UK, Poland and the Netherlands.

Annex 1.2 to this chapter presents indicators of productivity. Again one observes very important differences among member states, reflecting differences in production systems. Average dairy cow productivity in the most productive EU MS is 3.5 times that of the least productive MS. In 2006 Jongeneel and Ponioen (2006) indeed noted that eight out of the ten then new MS (EU-10) jointly produced about 20% of total EU-15 milk production and that large differences exist between the eight EU-10 and the EU-15 in terms of prices, production methods, milk yields, product quality, farm structures, farmers' and consumers' income, etc. Among the EU-10 Poland is the largest producer but has a low milk yield, while Hungary and the Czech Republic are smaller producers but with milk yields comparable to those in the EU-15. Beef production is closely linked to dairying, with specialized beef production hardly playing any role. However, since 2004, specialized beef production (suckler cows) develops in Central Eastern European Countries (CEECs) and plays an increasing role in less favored areas (such as mountainous regions). Dairy productivity in the two most recent MS, Bulgaria and Romania, is still well below that of all other MS. The three

Scandinavian MS clearly have highest dairy productivity, indicating the presence of modest size, but very intensive dairy sector.

Apart from some exceptions, animal productivity of beef and pig meat is of a similar order of magnitude, which regarding the very different maintenance/feeding costs of the respective animals clearly indicates the structurally higher productivity of pigs.

2.1.3. Imports and Exports

While gross trade flows between the EU and the rest of the world (taken from FAO trade statistics) often represent a substantial share of the EU production, net flows are generally low. Total meat exports from the EU represent over ¼ of EU meat production, but the net export flow is currently only just over 1%. The individual situation for beef, pork and chicken is similar: over ¼ of production exported, but a net import flow representing 3 to 4% of production for beef, a net export flow of 4 to 5% for pork and a net export of less than 2% for chicken. Small ruminant meat represents a more substantial net import, representing 16% of EU production.

Net trade of egg products is not significant, while that of milk products was not assessed since it takes to a large extent place in the form of transformed (milk powder) and second order products, mainly cheese. According to Chatellier (Chatellier and Jacquerie 2004), the EU15 (representing the vast majority of milk production as seen above, and a still higher share of international trade) exports some 10% of its dairy produce. Since the EU also imports a lower, but significant amount of dairy products (mainly Swiss cheese), the net export is again not a very important driver for the sector. Although the cited 10% would represent nearly 35% of international dairy product trade, this share decreases at the benefit of Oceania (Chatellier and Jacquerie 2004).

2.1.4. Trends

EU dairy production is very stable, largely as an effect of the milk quota system, but this hides important trends. Due to the milk quota system, productivity gains in milk yields lead to a continuing reduction in the total number of dairy cows in the EU. In general, dairying in the EU continues to intensify and specialize, with herd sizes of individual farms increasing in all MS. Together this means that production continues to concentrate on fewer, larger farms (e.g. about 50% of EU dairy cows are in herds of at least 50 heads) resulting in a corresponding decrease of dairy farming on many holdings and in some cases abandonment of holdings. This is true for virtually all dairy farms irrespective of system or bio-geographical region; noting that 85% of EU milk production is derived from one high input/output (see CEAS, 2000) economic/technical class of dairy farming, except where national authorities actively seek to help maintain small producers or promote organic production (e.g., Austria), such as some in mountain areas.

Since the introduction of the milk quota in 1984 large decreases in the number of dairy cows occurred and this trend is still ongoing. Between 1995 and 2003 dairy cow numbers declined on average by -15% in the EU15, with biggest decreases in Spain (-19.2%), Austria (-17.7%) and Germany (-16.9%). In the EU27, the average decrease in numbers of dairy cows was -6.3% between 2003 and 2007, with biggest reductions occurring in Portugal (-18.7%), Slovakia (-14.9%), Finland, Spain, Czech Republic and the United Kingdom (all around -11%) (Eurostat 2009).

Some words need to be spent on changes in EU-10. The transition from central planning to a free market brought severe shocks to the livestock sectors of these transition economies. On the demand side shocks were induced by rising consumer prices and falling real income that came with price and trade liberalization. On the supply side, producers faced falling output prices and sharply rising prices for feed and other inputs. Producers also had to adapt to fundamental changes in the markets for land, labour, and capital that came about with the transition (Bjornlund, Cochrane et al. 2002). In all Central and Eastern new MS the number of dairy cows declined significantly between 1991 and 2004, e.g. in Latvia by about -68%, and in Estonia, Czech Republik and the Slovac Republic by more than -50%. An even sharper decline occurred in the beef sector, where production declined by about -85% in Latvia and by more than -65% in Estonia, Czech Republik and Hungary. An exemption is made by Slovenia, where beef production showed an increase by more than 50%. In the same time period (between 1994 and 2004) the pig sector experienced also sharp production decreases in the Central and Eastern NMS, most pronounced in Bulgaria (-75%) and Latvia (-70%). In contrast to the decreases in dairy cows, beef and pig production are significant increases in poultry production in most new MS. While Latvia shows also a decrease in polultry production of more than -90% and Estonia by almost -40%, all other NMS increased their poultry production between 1991 and 2004, with biggest increases in Poland (+170%) and the Czech Republik (+140%) (CAPRI database, 2010).

2.2. Farming methods and farm structure across the EU

2.2.1. Large ruminants

Dairy farming systems remain characterized by an important diversity, despite the strong afore mentioned restructuring (the number of dairy holdings in the EU15 is now well below the one observed in France in the beginning of the 1970s), technical modernization and the wide adoption of the Holstein race (Chatellier and Jacquerie 2004). Most salient aspect of this heterogeneity is the substantial variation in size (surface, herd and quota), making it hard to compare small units from the southern EU (but also Austria) with large units dominant in the UK, Denmark and the Netherlands. The heterogeneity also expresses itself through the natural production conditions, labor conditions, the (feed) resource base and the intensification level. The level of specialization also varies markedly between regions. The application of milk quotas and the development of different business forms constituted an incentive for diversification towards annual crops, landless animal production or beef production (Chatellier and Jacquerie 2004).

The average milk quota per farm also varies strongly between dairy regions. Less than 160,000 kg in Austria, Spain, Italy, Finland, Portugal and south Germany (Bayern), milk quotas exceed 400,000 kg in the UK, Denmark, the Netherlands and Eastern Germany. Dairy farms in the latter region are a rather special case for the EU: while of a very large size (664 ha and 1.3 million kg quota) and an important paid labor force, productivity is low and dependence on direct public aid is high (Chatellier and Jacquerie 2004). While representing only 11% of EU15 dairy farms in 2004, these over-400,000 kg quota farms produce 39% of milk supply. Still the number of under-100,000 kg quota farms remains important at EU level (38% of EU15 dairy farms in 2004, representing 10% of production). They are predominantly encountered in the southern dairy regions of the EU and in

Austria. The number of registered dairy cow holdings with relatively low levels of cow numbers substantially increased since the EU enlargements. This highlights a 'long tail' in the structure of production whereby a majority of total dairy holdings are relatively small in terms of cow numbers and contribution to total EU production. These farms are probably less specialised than those accounting for the majority of production with dairying being one of a number of enterprises (mainly other livestock enterprises) undertaken. However, to these farms dairying as an activity remains an important part of total economic activity.

2.2.1.1 The transition economy member states

Without contradicting the above statement on the long tail due to enlargement, the situation of dairying in the Central and Eastern European (CEE) countries that entered the EU in 2004 and 2007 should not be seen as uniformly dominated by small holdings. Among the countries of the 2004 enlargement, Poland is by far the largest country in terms of population, area and milk production. However, the average milk yield in Poland (4.0 ton/cow in 2002) is about 500 kg below the average in the eight CEE MS, and about 65 per cent of the average yield in the EU-15 (6.1 ton/cow in 2003). This relatively low milk yield is indeed the result of the large number of very small non-specialised farms in Poland, producing partly for own consumption and using mainly grasslands for feed (Jongeneel and Ponsioen 2006). But the two countries among the eight CEE MS with the highest average yields, Czech Republic and Hungary (about the EU-15 average), are the second and third largest milk producers, respectively, in the group. In these countries there are many large collective and cooperative farms, which use more modern technologies and concentrated feedstuffs as an important part of the feed ration. 95 per cent of Hungary's milk production meets EU hygiene standards, and similar high levels are reached in the Czech Republic (Jongeneel and Ponsioen 2006). The differences in average yields between most of the CEE MS and the EU-15 remain large, which suggests that a large increase in yield is still possible and expected. A significant part of the milk production in the eight CEE MS is not processed in the dairy industry but either directly marketed or consumed by the farm family. In Latvia, Lithuania and Poland, only about 45% to 65% of the milk production goes to dairies. Reasons for this include low quality of the raw material and high milk collecting costs. In Romania, most livestock is held on peasant farms averaging half a hectare in size. Production is primarily for subsistence purposes, and very little is marketed. Upon the transition to a free market, farmers, no longer able to afford a balanced feed mix for animals, sharply reduced the use of costly mixed feeds, switching to less expensive feeds that are poorly balanced with proteins and other supplements. Cattle producers turned away from relatively expensive concentrated feed in favour of forage crops and pasture grazing (Bjornlund et al., 2002).

In contrast with these subsistence situations, the share of deliveries to the dairy industry in the Czech Republic and in Slovakia is almost the same as that in the EU-15, around 95% of milk production. In these countries, the dairy processing industry is relatively well developed and modernised (Jongeneel and Ponsioen 2006).

2.2.1.2 Dairy systems

Box 2.1 provides a description of the functioning of an average dairy system in the UK, extracted from Garnett (2007), illustrating the complexity of dairy farming as practised on EU market oriented holdings throughout the EU.

This general scheme also illustrates the fact that variation in dairy systems is strongly related to feeding strategies and thus influenced by bio-physical conditions. Bos et al. (2003) distinguish two general types of dairy farming with regard to climatic conditions. In Northern Germany, Denmark and Sweden the predominant strategy is to increase milk yields per cow. A high level of concentrate feeding strongly contributes to high milk yields. This strategy is mainly due to the relatively short grazing season (5-7 months). Where climate is characterized by mild winters and high amounts of precipitation (Ireland, Western England, Brittany), milk production is based on a long grazing period on permanent grassland. Also the alpine regions are characterized by permanent grassland, but this is because arable farming is not possible in mountainous areas. In these grassland based dairy farming systems, the achievement of high milk yields per cow by means of concentrate feeding and breeding for high milk yield is generally a less important objective than maximizing milk yields from grassland.

Many other factors influence the strategy followed by the dairy farming system of a particular country or region. Bos et al. (2003) provide a synthetic description of the resulting strategy for a selection of countries and regions which have been annexed to this report (see Annex 2 to this chapter).

The two general types described by Bos et al. also constitute a first order discrimination in the typology proposed by the Centre for European Agricultural Studies (CEAS 2000) for the EU15, distinguishing high input/output from low input/output systems (Box 2.2 and Box 2.3).

Contrary to Bos et al., who claim a strong link between these two main strategies and climatic conditions, CEAS (2000) claim that "systems are more influenced by market constraints than physical constraints. As a result, farms of different dairy systems frequently occur contiguous with each other." But as Figure 2.1 shows they do discriminate at a second hierarchical level different high and low I/O systems for three main biogeographical realms.

Some characteristics of the Mediterranean high and low I/O systems represent differences with respect to the dominant "Atlantic" characteristics of Box 2.2 and Box 2.3 which are important in the environmental context of our study. Mediterranean systems probably account for only 7% of total EU15 dairy cow numbers and about 5% of total EU15 milk production. The commercial specialist systems (the high I/O system), where 50-60 head herds are common, tend to keep cows indoors all year round with zero grazing. On mixed farms (the low I/O system), where herd size can be as low as 10 head, stocking rates tend to be low (under 1.0 LU/ha). Feed in the commercial farms comprises a mix of farm grown roughage (a mix of maize and ryegrass silage and alfalfa hay). On the mixed farms grazing is used for 3-4 months per year in the spring with feed for the non grazing seasons derived from traditional polyculture systems (mix of tree crops, vegetables and cereals). The latter system makes very little use of mineral fertilisers (slurry and manure are however widely used in the forage cultivation system). On the commercial dairy farms there is widespread use of irrigated maize silage and dry-land ryegrass growing which is cut 2-3 times per year.

Box 2.1: The UK Beef-Dairy system

The UK Beef – Dairy system

On average, dairy cows calve once every 385 days, and give birth to either a pure dairy or a ‘beef cross’ calf. In the latter case the father will be chosen from a beef breed. Dairy herds need to be restocked at the rate of roughly 20% a year to replace cows that no longer produce milk (as a result of old age, ill health, or poor yield). In order to achieve this 20% replacement rate, roughly half the best yielding dairy cows are impregnated with the semen from a dairy bull, although the proportion varies by system and year. Dairy cows that have reached the end of their productive lives are slaughtered and enter the meat chain. However their bodies yield very little meat as they have been bred in such a way that all their energy is directed into milk production. The remaining milk cows are crossed with beef bulls, such as Charolais, Hereford and Aberdeen Angus breeds and their offspring reared for human consumption. In addition to these cross-breeds the pure dairy bred bull calves, born as a by-product of dairy heifer breeding, are also generally fattened as beef bulls or steers (neutered males).

Suckler beef on the other hand is obtained from cattle bred specifically for their meat yielding properties. These properties include the quality and quantity of muscle they put on (conformation) and the efficiency and rapidity with which they grow. A suckler calf is the offspring of a pure bred male (sire) and either a pure bred beef female (dam) or a beef-dairy cross. In other words they are of between 75-100% pure beef pedigree. The calf is fed on mother’s milk until it is weaned at about 6 months. It can grow rapidly (up to 1.5 kg/day), and produces a high quality carcass. The weaned calf is referred to as a store animal and is either finished by the breeder or is sold on to another farm.

Some of the male beef cattle are castrated, partly to avoid unwanted breeding where cattle are raised in mixed sex groups and partly because steers are less aggressive, easier to manage and can be reared outside with less difficulty – bulls charging around the countryside tend to be fairly unwelcome. On the downside steers have a slower growth rate than their uncastrated counterparts. Bulls are generally kept inside and slaughtered by the age of 12-15 months whereas steers and heifers take around 18-24 months to reach slaughter weight.

Feeding the dairy herd:
A dairy cow will consume an average of about 20-22 kg dry matter a day, although in some high-yielding systems she can eat up to 28 kg. While grass is the best way, economically speaking, of feeding an animal it cannot provide the most concentrated nutrition, hence the use of other bought-in feed. In particular, a high yielding dairy cow cannot satisfy her metabolic requirements from a forage-based diet alone and as the proportion of high-genetic merit cows (cows with high milk yield potential) has increased (as cow numbers have fallen) so has the reliance on dietary supplementation.

Other sources estimate that, for dairy cows, between March and September about 50% of their diets (dry weight matter) consists of fresh forage and the remainder of prepared feeds. In the winter, 50% of their feed is silage and 50% concentrates. Expressed in terms of energy, the grass/silage element makes up roughly 40-45% of the diet; in terms of energy protein the grass:concentrates ratio would be 30:70. Another source estimated that, averaged over all the feeding systems, around 75% of the diet of ruminants is supplied by forage (including silage). A later paper by the same author, however, gives a lower figure of 60%. The reason for this discrepancy is that the use of compound feed for ruminants increased over this time, and continues to increase. Clearly the variation in estimates reflects the range of different systems and different farmer preferences.

Feeding the beef herd:
As noted, pure dairy-bred calves also enter the meat chain; indeed, these calves account for 65% of all meat output. They will be reared for the first 12 weeks of their life on formula milk and concentrates. Some will then go onto store producers (kept on silage and grass for 3-9 months before being sold on to finishers). Others will go directly to semi-intensive finishers and will be fed grass during the summer, and silage and concentrates during the winter. Others will go to intensive finishers where they will consume a mixture of oilseed cake, straights and straw. 45% of dairy calves are ready for slaughter by 20 months, 25% within 2 years and only 15% will be reared for a longer period than this.

Source: (Garnett 2007)

Box 2.2: High input/output systems

High input/output systems

a) **Locations**. The Netherlands, England, SW Scotland, La Mayenne region of France, Western and SW France, Northern Italy, Sweden, Finland, Northern Spain, Denmark, Germany.

b) **Production**. These systems account for 83% of total EU dairy cow numbers (about 18.5 million head) and approximately 85% of total EU milk production (about 96 million tonnes).

c) **Structure**. They are characterised by having relatively large average herd sizes (e.g., over 70 cows in the UK, but within a range that falls to about 44 cows (the Netherlands). These systems are also where most specialist dairy farms are found (data deficiencies preclude the provision of supporting data).

d) **Intensity**. Stocking rates tend to be high (e.g., over 2.0 LU/ha/year but can be as low as 1.4 LU/ha/year), supported by relatively intense fertilisation (150kg N/ha to 300kg N/ha), use of buffer feeds (zero grazed grass (e.g., former East Germany), maize silage and brewers grains are commonly used: e.g., maize silage accounting for over 25% of the main fodder area) and use of concentrates which are usually fed to yield in the milking parlour (especially in the 'industrial' production systems of East Germany). Winter feed tends to consist predominantly of maize silage, although grass silage is used in regions such as Finland and Sweden where the climate is not suited to growing maize. Winter feed is supplemented with products such as cereals, brewers grain and wet beet pulp fed as straights or via concentrates.

e) **Calving**. Tends be all year round with a slight bias towards spring in certain countries, such as the Netherlands, in order to maximise the use of peak grass growth in spring and to match peak milk production to the perception that prices are usually higher in the summer and have traditionally been so. More northerly Member States such as Finland and Sweden have a slight bias towards autumn calving (August to October). Variability in calving by location is significant even within zones, regions or countries.

f) **Housing**. Cows are housed in the winter months (up to 8 months of the year in the more northerly parts of the EU) and in certain cases may be housed overnight in autumn and spring. The harsher the conditions, the longer the winter housing period becomes. In Finland and Sweden the period spent housed is even higher (between eight and ten months, depending on latitude), but is constrained beyond this by animal welfare legislation which stipulates a minimum outdoor grazing period. The extreme form of housing can be found in the 'industrial' units in parts of the former East Germany (the new Länder) where cows are sometimes permanently housed.

g) **Replacement/age of herd**. Average herd age tends to be young which implies a relatively high replacement rate.

h) **Breed**. Specialist dairy breeds of which Friesian/Holstein dominates (ie, variants of which e.g., British Friesian, Holstein (Prim'Holstein in France), Dutch Holstein). These account for almost all of herds (over 95%).

Box 2.3: Low input/output systems

Low input/output systems

i) **Locations**. This type of system is essentially associated with the main form of dairy production in Ireland, although variations to this exist in some other regions such as the northern and western extremities of the UK, parts of northern and eastern France, some of the Azores and throughout the Atlantic and Continental zones (see section 3) where producers have taken up 'organic' production systems.

j) **Production**. These systems probably account for 6-8% of total EU dairy cow numbers (about 1.3- 1.75 million head) and about 4-5% of total EU milk production (about 4.8-6 million tonnes).

k) **Structure**. Farm sizes can fall within a broad range of 20 to 80 ha. Accordingly average herd size also falls within a fairly broad range (25-70 cows, with an average of about 30 in Ireland (the main location). These systems include some specialist dairy farms and organic producers but mainly comprise mixed farms in which other livestock enterprises are practised (data deficiencies preclude the provision of supporting data).

l) **Intensity**. Stocking rates tend to be in the range of 1.0-1.4 LU/ha (1.9 LU/ha in Ireland). Where organic systems are practised stocking rates fall to about 0.8 LU/ha. Less than 30% of farmed land tends to be used for forage (mix of cereals and brassicas), with the rest being permanent grassland. Forage areas are supported by fertilisation levels of about 50-100kg N/ha (zero use in organic systems). Grazing is an important part of the feeding regime with use of concentrates not usually higher than 500kgs/cow. Winter diets tend to comprise a mix of grass and maize silage and hay and the summer diet is dominated by grazing. In organic systems areas of fodder beet and arable crop silage may be only half the corresponding area under conventional systems with greater use of clover and lucerne based silage.

		FODDER AND FORAGE RESOURCES (LAND USE CATEGORIES)				
CATEGORIES OF PRODUCTION AND REGIONS		*SEMI-NATURAL PASTURES*	*GRASSLANDS*	*CROPS & GRAIN MIXED*	*CROPS & GRAIN MAIZE*	*LIMITED GRAZING*
CONTINENTAL ATLANTIC BOREAL MACARONESIAN	*HIGH INPUT/OUTPUT*		G1 INTENSIVE GRASSLAND SYSTEMS (LEYS) GRASS 60% + CROPS	CG1 CONVENTIONAL MIXED SYSTEMS CROPS 50%+	M1 INTENSIVE MAIZE SILAGE SYSTEMS MFA = Maize 25%-60% CROPS 50%+	L1 INDUSTRIAL
	LOW INPUT/OUTPUT		G2 PERMANENT GRASSLAND SYSTEMS (Lowland) GRASS 80%-100%	CG2 LOW-INPUT AND ORGANIC MIXED SYSTEMS		
ALPINE AND BOREAL	*LOW INPUT/OUTPUT*	P1 TRANSHUMANT SYSTEMS	G3 PERMANENT GRASSLAND SYSTEMS (Mountain) GRASS 80-100%			
MEDITERRANEAN	*HIGH INPUT/OUTPUT*					L2 MEDITERRANEAN COMMERCIAL SYSTEMS
	LOW INPUT/OUTPUT			CG3 MEDITERRANEAN MIXED SYSTEMS (SMALL SCALE)		

Figure 2.1: EU dairy systems

2.2.2. Small ruminants

The number of sheep and/or goat holdings is important and exceeds the number of dairy or even cattle farms in general in the Mediterranean MS (incl. Portugal, but excl. Slovenia), as well as in Bulgaria, Romania, Hungary, Czech Republic and even in the UK. But farm herd sizes are generally small, output levels low and statistics and studies describing EU small ruminant

production systems very scarce. They play an important role in the subsistence mixed farming systems of the countries from Central Eastern Europe, but here information is very limited and often unreliable. Many breeds are adapted to living in harsh conditions and to feeding on coarser grasses, so they can often be found in poorer and more rural parts of the EU. Most of the remaining herd is primarily dedicated to milk production, but again because of the small holding size, as well as the frequent on farm or otherwise local transformation (milk is nearly exclusively used for cheese), production data are scarce. Much of the cheese production takes place under certified and controlled labels, generally limiting the scope for very intensive systems. Grazing is generally important, with farm grown roughage supplementing in the too cold or too hot and dry periods. A variable level of complementary concentrate feeding is common in milk production oriented small ruminant systems.

2.2.3. Pig

EU monogastrics production is generally an intensive, indoor, large scale business which combined with the much weaker dependence on the local resource base and bio-physical conditions leads to a relatively low level of variability in production systems. Both pig and poultry play an important role in mixed livestock small holdings throughout the EU, particularly in the CEE MS, but this system represents little in terms of overall herd size and still much less in terms of contribution to overall production (which strongly contrast with e.g. the situation in the world's largest pig producer China where still well over half the production originates from such small holder systems.

Pigs are raised to produce piglets or to produce meat. Sows raised for breeding are housed in different systems from pigs raised for meat -- fattening pigs. Weaning usually takes place at four weeks, after which piglets are mixed with other litters in special housing systems for weaners. The average EU litter size is roughly 11. When the piglets have reached approximately 30 kg in weight, they are often moved to other accommodation to finish their growth before slaughter takes place at 5.5 to 6.5 months of age. In most EU countries, the live weight at slaughter is between 105 and 115 kg (Reuters 2007). In contrast with poultry production, pig farming is a far less integrated industry. In the UK only about 5% of breeding pigs and 28% of rearing and finishing pigs are grown on farms under the direct control of processors; the majority are reared on independent farms. Many of these are, however, contracted to a processor, some directly but the majority through producer groups (Garnett 2007).

Pigs consume both prepared compound feed and by-products from other parts of the agricultural and food industries. Drawing again from Garnett' description of the UK situation, valid for a very large part of EU production (Garnett 2007) pig compound feed is largely made up of cereals (60%) and oilseeds and pulses (29%). The remaining 11% is comprised of oils, vitamins, minerals and amino acids. Co- and by-products will vary according to availability and include biscuit fragments, whey, yoghurt tank washings and brewing by-products. Approximately 30% of pig producers currently use liquid feeds as opposed to dry compound feed or home-mixed rations. Liquid feeding is not new to the industry, but UK producers have been slow to take advantage of it, mainly because of the high capital cost of conversion. Liquid feed is made of whey or potato starch with cereals, oil meals and various vitamins added. There are three main stages in pig rearing. The first encompasses activities to do with breeding, gestation and farrowing. The pigs are then weaned, at which point they move onto the second or nursery stage. After this they enter the final or 'finishing stage'. Each

stage in a pig's life requires a different diet. While some farms will undertake all stages in the pig rearing process, others may focus on just one or two of the stages.

One of the few pig farm system characteristics that varies considerably throughout the EU is farm size. Monteny et al. (2007) provide size distribution information for each MS. While the majority of farms, also in the most important producing countries Spain and Denmark, generally have a few hundred fattening pigs, there is generally a small fraction exceeding the IPPC threshold (>2,000 fattening pigs; >750 sows), contributing very significantly to overall production. While representing only 0.3% of EU fattening pig farms, they contain 16% of the population. 41% of the population is contained in holdings with over 1000 heads, representing 1.0% of the number of holdings. Sow farm figures are rather similar. Virtually all MS have a substantial portion (>>10%) of their pig population in such large farms, a notable exception being Poland with only 4% of fattening pigs and 5% of sows in IPPC farms, and more surprisingly also France (7% of each) and Belgium (7 and 3% resp.). In the CEE MS some extremely large holdings can be found. In Romania for example, following the transition from a centrally planned to a free market economy, large cooperatives were liquidated early and land restituted to its former owners. However, most state owned farms continued to exist and to benefit from subsidies not available to private farms. As of 1997, 34 percent of the hogs and 19 percent of poultry numbers were still raised on these state farms. The state livestock complexes were huge, vertically integrated enterprises. Some of them had as many as 800.000 hogs (i.e. some 12% of the national pig population on one single "farm"!). They typically engage in every stage of the production chain: farrow to finish, slaughtering, processing, and even retailing. Many of these farms are located in the prime grain-growing regions and produce their own feed as well (Bjornlund et al., 2002).

2.2.4. Poultry

The main characteristics described for monogastrics in the preceding section apply to poultry production: Poultry meat tends to be produced away from the land, in barns or other enclosed shelters, although outdoor husbandry is increasing gradually. Feeds are made up from locally grown or purchased ingredients, often grain-based, or bought in as prepared "compound" feedstuffs (Reuters 2007). Most of the chickens we eat are raised in intensive systems in large purpose-built houses, on deep litter of chopped straw or wood shavings. Chickens are kept for about 6 weeks, until they reach a weight of around 2.2 kg. Turkeys are slaughtered at around 20 weeks when they weigh 13 kg. The main contrast with the pig sector, as also stated above, being its higher level of integration. The mainstream broiler industry is highly integrated and concentrated. The processor companies often own or control all stages of production, from the supply of day-old chicks (they also usually own at least some of the breeder capacity and hatchery facilities) through feedstuff manufacture and supply to delivery of the poultry meat to the retailer. 60% of broiler chickens today are grown on farms owned directly by processors; the rest are grown by independent farmers, almost all of whom are contracted to a processor (Garnett 2007). Of the raw material input to the chicken feed milling sector, about 89% consists of cereals, soy, oilseeds and pulses.

Concerning layers, the majority of the eggs produced in the EU come from caged systems. In already standing conventional caged systems, a minimum of 550 cm^2 per bird is required. However systems built since 2003 must allow 750 cm^2 per bird and the cages be 'enriched,' as it is called, with a nest, perching space and a scratching area. Food is supplied in troughs fitted to the cage fronts and an automatic water supply is provided. The units are kept at an even temperature and are well ventilated. Electric lighting provides an optimum day length throughout the year. In the UK

barn systems produce around 7% of eggs (Garnett 2007). Here the hen house has a series of perches and feeders at different levels and the stocking density must be no greater than 9 hens per square metre of useable floor space. The free range system is the third alternative; this produces around 27% of eggs produced in the UK.

Concerning farm size the situation is rather similar to that of pig holdings (see above). The situation is still more extreme though. In the EU, IPPC poultry farms (>40.000 head) represent only 0.1% of laying hen farms, but contain 59% of the laying hen population (Monteny et al., 2007)! For broiler farms these figures are resp. 0.5% and 64%. In Greece, Ireland, Austria and Finland the laying hen population in IPPC farms represent less than 30%, while this is more than 70% in Spain Italy, Czech Republic and Slovakia: the absence of a spatial pattern hints at the “landless” character of production. Moreover for broiler the situation is similar, but high and low share MS are not the same.

During transition poultry fared better in Poland and Hungary than in the other CEE countries. The declines were much less, and, after 1993, poultry output began to grow in both countries, particularly in Poland. Several factors account for the growth of poultry output in Poland and Hungary. Consumers began to substitute lower priced poultry meat for beef, and producers were able to respond quickly to that shift in demand. In addition, a large share of poultry production was private in both countries before the transition (Bjornlund et al., 2002).

2.3. Conclusions

The overview provided by this chapter, largely restricted to characteristics at national level, provides a broad but good understanding of the EU livestock sector’s complexity. Throughout the EU the livestock sector is a major player of the agricultural economy and its land use is massive. The relative importance of different sub sectors 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). Then within each sub sector a range of production systems occurs.

3. TYPOLOGY OF LIVESTOCK PRODUCTION SYSTEM IN EUROPE

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3.1. Introduction

Developing a typology of livestock production systems (LPS) is challenging and requires identifying the main relevant criteria that have qualitative and quantitative impact of gas emissions. LPS diversity is described by a range of farming characteristics among them (i) animal species and numbers, (ii) targeted production sector i.e. specialisation, (iii) intensification of livestock production and (iv) manure management strategy coupled to cropping system are perceived as priorities when classifying LPS (Burton & Turner, 2003). The main farm characteristics considered in this study are shown in Figure 3.1. Quantification of farm functioning was done on the basis of the FADN dataset differentiating by six main animal products:

- BOMILK as dairy cattle for milk production
- BOMEAT as meat production from bovine livestock
- POUFAT as the meat production from poultry (broilers…)
- LAHENS as the egg production from hens
- SHGOAT as the meat and milk production from sheep and goats (ewes…)
- PORCIN as the pig activity concerning the meat and the rearing (sows) activities.

The typology, developed in this chapter, will be also used for an aggregation of the LCA results in order to highlight relationships between farming systems and GHG emissions. We will do this for the two most important sectors with respect to GHG emissions, i.e. the BOMEAT and the BOMILK sectors.

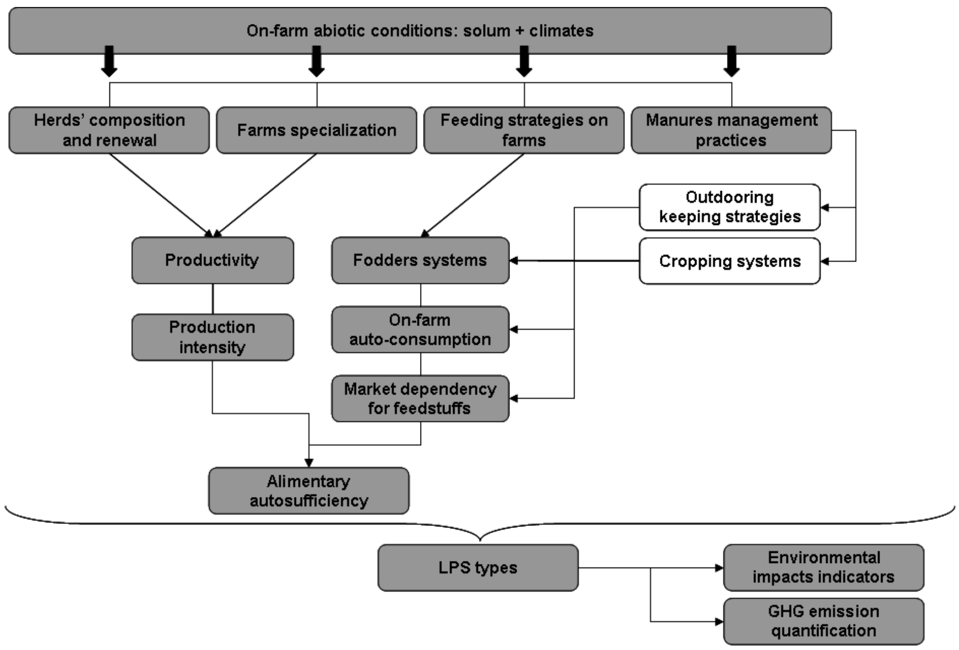

Figure 3.1: Main farm aspects considered of interest during the LPS typology workflow in order to attribute potential environmental impacts and GHG emissions per LPS type

3.2. CAPRI Modelling System and data availability

As also the quantification of GHG emissions from European livestock production (see chapters 4 through 8), the development of the EU LSP typology is based on the CAPRI model. Modules of particular interest for the present chapter are the FEEDING and FERTILIZING modules in which all input/output livestock-related activities and practices are considered, the FARM TYPE module which is mainly dedicated to main agricultural activities identified in a region and the environmental indicators module. The FARM TYPE module does not give farm types as defined in FADN, but farms are classified according to 50 possible agricultural activities. Only the major five representative activities in a region are considered, while remaining farms are lumped to a sixth, residual group. Despite the high number of explicative variables within the CAPRI database that could be used, unfortunately, detailed information on manure management systems at the regional level was missing.

This chapter is based on ex-post data from the CAPRI database for the year 2002, available for 243 regions that CAPRI is considering in EU-27 + Norway.

3.3. LPS descriptors and regional zoning

The descriptors used for classification of regional LPSs for the six different livestock production sectors considered can be grouped into 8 different categories listed below. 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 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. Then, four successive steps of the classification methodology were applied (Multivariate platform, Principal components analysis (PCA), and a two-way hierarchical ascendant classification (HAC).

The eight dimensions considered are:

Animal assemblages and livestock herd diversity to characterize regions according to the assemblages observed of the six different livestock sectors considered. To describe the animal assemblages we had recourse to an ecological method based on the calculation of the index of similarity between two herds situated in two distinct European regions (Morisita's index of similarity). To verify classification of regions from animals' assemblages we decided to compare our results to the Eurostat farm type data at regional level, considering farm types based fully or partly on livestock production.

Climate data to describe regional agro-ecological situation

Intensity level has been expressed in different ways: (i) as the total costs (€) and the proportion (%) over the total cost of production of money dedicated to feedstuffs and veterinary products and (ii) as the stocking density (for grazing livestock)

Productivity level: total revenue per livestock sector, revenue per head or per livestock unit, or again percentage of the total livestock revenue coming from one specific livestock sector (revenues from crops were also used)

Cropping system is described as the true area or the proportion of the total regional agricultural area used to grow one specific crop (sunflower for instance) or a family of crops (cereals for instance)

Manure production: no information concerning the storage and spreading systems in use in region, we focused onto the quantity of manures (total or N, P, K) produced by livestock sector.

Feeding strategy: apart from the money spent for feedstuffs purchasing which is available in CAPRI, feeding strategy cannot be directly calculated because of the lack of knowledge considering on-farm auto-consumption of crop's products. In this special case, we calculated the proportion of grazing animal energy and protein annual requirements which could be covered by the use of the sole fodder crops – it conducted to the obtaining of a fodders-energy and -protein autonomy of the regions.

Environmental impact: as an output of the CAPRI-dynaspat simulation platform, total N-P-K from manures was confronted to total N-P-K plants' requirements to determine the potential utilization which could be done of the manure to fulfil plants requirements (N-P-K) i.e. regional N-P-K autonomy and the risk of N-P-K surplus in a region; the latter being considered as an indicator of the risk of ground- and surface-water pollution by nitrate and phosphate from livestock activities.

We considered specialization of a farm by combining information on both the cropping and the livestock production systems. Additionally, each region/country was assigned an identifier for GIS processing.

The following descriptors were not available in the CAPRI database and was complemented by data from JRC Agri4cast action (climate), INRAtion© (feeding strategy) and Eurostat (farm types):

Climate: Climatic data were extracted and processed from the current Crop Growth Monitoring System (CGMS) version 2.3 managed by JRC Agri4cast action. Complete description of the CMGS is use in JRC can be found in "The MARS Crop Yield Forecasting System" (Micale & Genovese, 2005). For the purpose of the GGELS project, a limited list of meteorological variables was used. These variables have been chosen as indicator for the climatic potential of a region for crop growth and animal welfare: cumulative sum of temperature ($°C.day^{-1}$, base temperature of 0°C), temperature (°C), precipitation (mm), photosynthetic active radiation ($MJ.m^{-2}.day^{-1}$) and number of rainy, snowy, frozen days. Some of them have been calculated as cumulative sum for the first 3, 6 and 12 months of the year (to proximate growing period duration and/or to match cropping system calendar).

Feeding strategy Despite the fact that data concerning animal energy, protein and lysine (for granivores only) requirements per animal are directly available inside 2002 CAPRI baseline database, the lack of explanation concerning the units used and the necessity to update feeding factors asked for a complete recalculation of the animals requirements. This was undertaken for each one of the eighteen livestock production activities considered inside CAPRI (DCOH, DCOL…); then requirements were calculated per herd and grouped to obtain total energy/protein/lysine requirements for each one of the six livestock sectors considered in GGELS. The method and main characteristics describing animal production and growth considered within CAPRI (Nasuelli et al., 1997) was respected. However, certain values were extracted from current literature (mainly for granivores) and from "Alimentation des bovines, ovins et caprins" (INRA, 2007) for grazing livestock.

Farm Type Because the abundance of farms per farm type of interest is provided at NUTS1 or NUTS0 level for certain countries (BE, NL, DE, AU) in regional Eurostat database, we have calculated the proportion (% of the total number of farm in a region) of the farms included in each farm types from NUTS0 or NUTS1 data and applied these percentages to each corresponding NUTS2 region.

Results from the regional zoning confirms the diversity of the livestock sector in Europe already addressed in Chapter 2 and is shown in the form of maps in Annex 1 to this chapter (e.g.: total agriculture revenue (B€) per region, share (%) of the livestock production in the total agriculture revenue, Regional share (%) of the plant production in the total agriculture revenue, Regional distribution of the total number of livestock units (LU), Regional distribution of the total nitrogen surplus (manures + fertilizer + crops residues) per hectare of arable land, eight main climates, five main elevation classes, eight cropping systems identified …).

Only the Animals' assemblage classification is provided here as example. It was performed using absolute abundance of livestock units per livestock sector from which the by-pairs of region Morisita's index of similarity has been calculated and compiled into a double matrix of similarity. From the automatic and successive HAC, ten clusters were decided. In parallel, the relative abundance (%) of each livestock sector in the total number of LU was calculated per region.

From these values, we have proposed a denomination of each one of the clusters by considering the two first livestock sectors participating to the animals' assemblages and by respecting the hierarchy of participation. Regional mapping of the final ten clusters is presenting in Figure 3.2.

The relevance of this classification has been later verified by comparing animals' assemblage in a region and European data. From Eurostat, the number of farms per farm types concerned by livestock production has been extracted for 2002. The share (%) of each farm type in the total number of farms was calculated and used to estimate if the animals' assemblage classification provides us a valid interpretation of the livestock production in region. Almost all the farm types considered are matching the clusters obtained from classification onto the animals' assemblages.

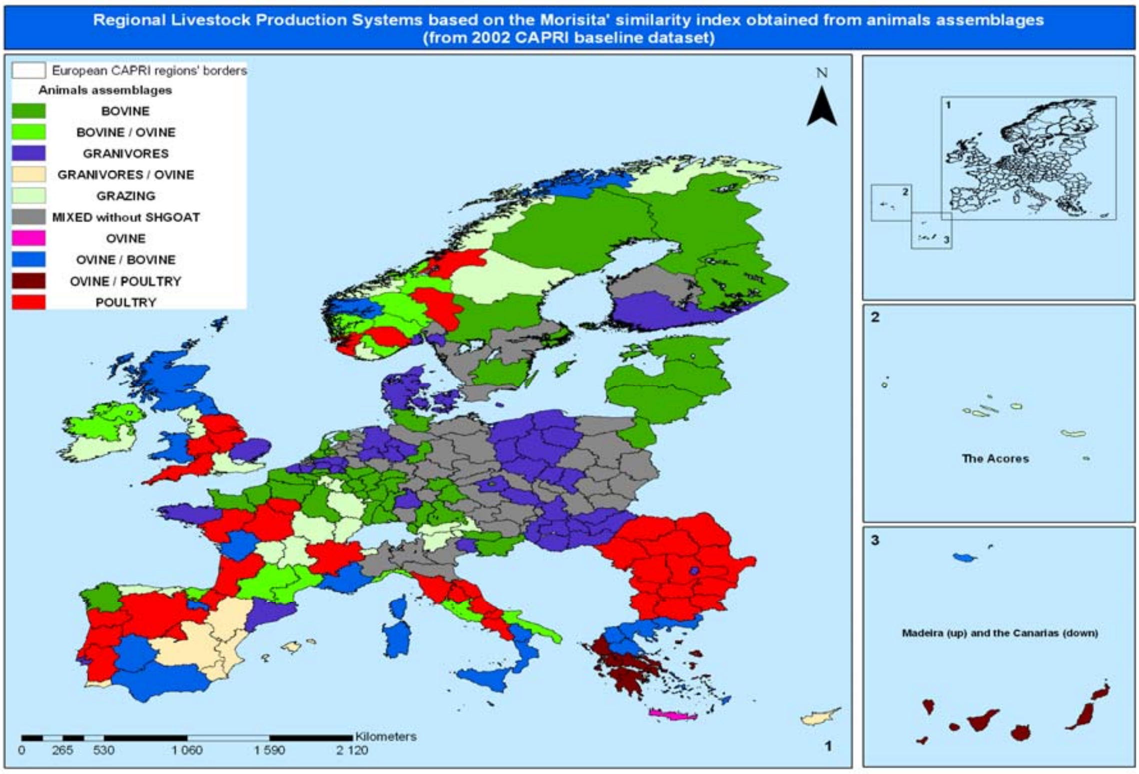

Figure 3.2: Animals assemblages mapping in EU-27 + Norway

3.4. Results of the LPS typology

In this chapter we focus on the results obtained for the BOMILK livestock sector as an example. Results of the other five LPSs are given n Annex 2 to this chapter.

<u>The BOMILK sector</u>

Classification over the whole set of regions on BOMILK production has been performed from nine remaining significant variables describing more specifically this livestock sector. Among all, the (BOMILK) herd size expressed in livestock unit was very strongly correlated (>0.95) to other quantitative variables such as total milk production, total manure or again total revenue and consequently only one was conserved. It was used in parallel of the relative participation of the BOMILK production to the total "livestock" revenue (%). The other seven descriptors are describing the feeding strategy adopted in region by focusing on the fodder activities.

Results from PCA pointed out that BOMILK revenues were generally correlated with the level of intensification, suggesting a positive relationship between the production and the magnitude of the investment spent for feedstuffs and veterinary products in the total cost of the BOMLIK production (Table 3.1). BOMILK systems based on fodder production have to a lesser extent recourse to market for feedstuffs supplies. From the third component it appears that the herd size can be largely increased when a higher part of the total UAA is cultivated with fodder maize. Finally, there is a

trend showing that from a certain threshold, higher herd size is (economically) conceivable if sufficient auto-supplying of feedstuffs is planned on farm.

From this, clustering has been performed and seven final clusters developed. To describe clusters particularities, analyse of variances of the nine retained variables was processed

Qualitative description of the seven BOMILK clusters identified is given within Table 3.2. The results of diversity of the BOMILK production systems are mapped on the following Figure 3.3. A detailed description of the obtained clusters is given in Annex 3 to this chapter.

Table 3.1: Results of the PCA – Varimax rotation onto the nine descriptors retained for the BOMILK production description and clustering

	PCA comp. 1	PCA comp. 2	PCA comp. 3	PCA comp. 4	PCA comp. 5
Eigenvalue	2.12	1.85	1.55	1.00	0.77
Percent	23.54	20.59	17.22	11.13	8.56
Cum Percent	23.54	44.13	61.35	72.47	81.03
Eigenvectors (after rotation)					
Herd size (LU)	0.06	-0.03	0.14	**0.89**	0.12
Intensification (€/LU)	**0.72**	0.43	-0.08	-0.19	-0.15
Intensification (%)	0.01	**0.87**	-0.25	0.19	-0.10
Stocking density (LU/ha)	0.05	0.04	**0.93**	-0.04	-0.10
Revenues fodder (%)	**0.80**	-0.12	-0.02	-0.01	0.28
Revenues BOMILK (%)	**0.78**	-0.11	0.15	0.24	0.06
NRJ Autonomy (%)	0.07	**-0.80**	-0.24	0.37	-0.04
Fodder grass (%UAA)	0.15	-0.05	-0.10	0.11	**0.95**
Fodder maize (%UAA)	0.02	-0.14	**0.71**	0.43	-0.01

Table 3.2: Qualitative description of the seven BOMILK clusters identified

Clusters	Production	Intensification	Housing system	Market dependence	Main feedstuffs used
1	Subsidiary	Intensive	Indoor	Very dependent	Marketed
2	Secondary	Extensive	Mixed	Independent	Pasture / Maize
3	Primary	Extensive	Indoor	Dependent	Haymaking
4	Primary	Extensive	Outdoor	Independent	Pasture / grazing
5	Primary	Intensive	Mixed	Dependent	Pasture / maize
6	Subsidiary	Medium	Mixed	Dependent	Haymaking
7	Secondary	Intensive	Indoor	Dependent	Maize

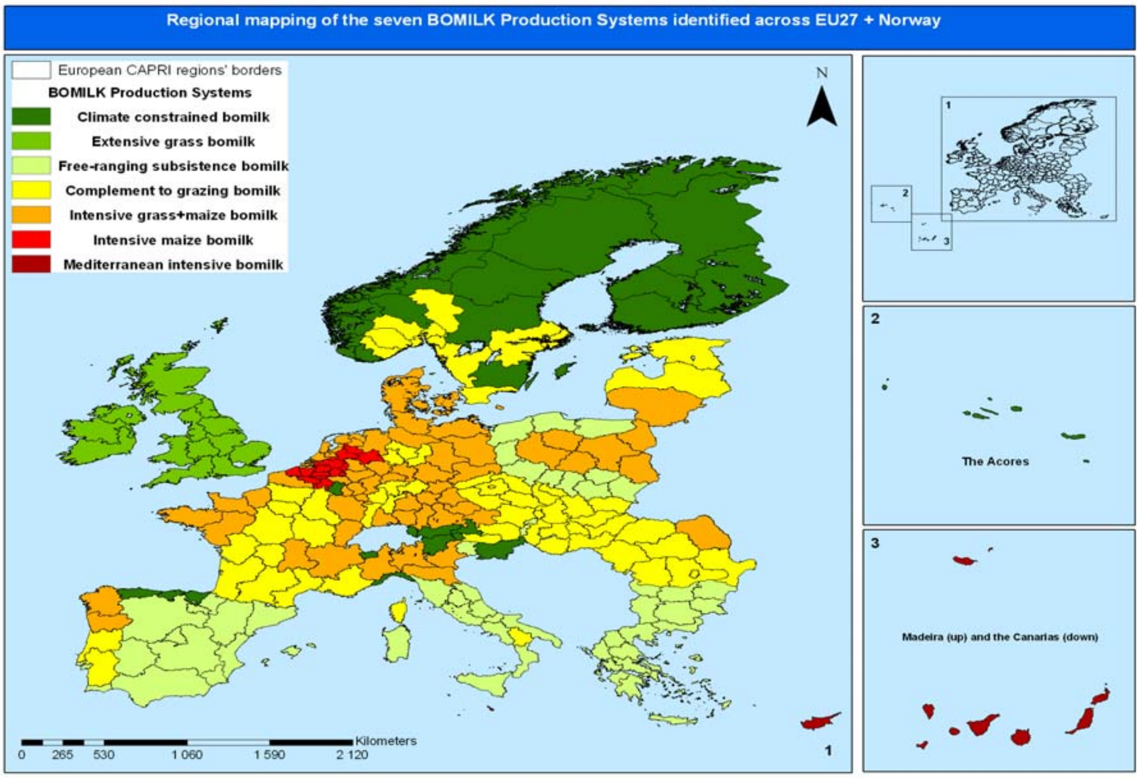

Figure 3.3: Diversity of the BOMILK Production Systems in EU-27 + Norway

3.5. LPS typology refinement using manure management practices information

An important factor with respect to GHG and NH_3 emissions from the livestock sector identified in Figure 3.1 are the manure management systems and manure application techniques. Unfortunately no official consistent reporting on manure management takes place under current EU legislation such as the Nitrate Directive. The only existing sources of information at EU level are two surveys collecting qualitative expert knowledge (MATRESA FP5 project, from 2001, covering all EU-27 except for Romania; one dating from 2004, covering EU25 (IIASA, RAINS model), with some additional information available from national submissions of GHG inventories to the UNFCCC).

To improve the situation, the JRC has contracted a study to CEMAGREF (France) to gather information on manure management (i.e. processing, storage and application) per farm animal species (Bioteau *et al.*, 2009). A questionnaire was developed and sent to about 400 experts across Europe having the knowledge for one or several specific regions. The so-called regions were the ones resulting from the “Climate & LPS association” described in the previous step.

Unfortunately, the number of questionnaires returned was low and did not allow a comprehensive description of all “regions”. Attempts were made to merge regions but the level of information not sufficient to derive consistent and appropriate information on manure management systems across Europe for the further development of the LPS typology and its use for the quantification of GHG and NH_3 emissions with the EU-wide CAPRI modelling system for GGELS.

Nevertheless, according to a study conducted along with the CEMAGREF study by the ‘Institut de l’élevage’ (France), sufficient information was available for some regions linked to the BOMILK sector (North of Italy, The Netherlands, Ireland, Austria, Czech Republic, Finland.). From the questionnaire answers, they have been able to derive the following information: solid and liquid manure fraction and fraction of time spent indoor/outdoor per season. An indication of the spatial validity of these values (regional or nationwide) is also given. Values are provided in Table 3.3. The data enabled the ‘Intitut de l’élevage’ to make some general observations:

- Mediterranean systems: almost no grazing, mainly liquid manure.

Mediterranean systems (like Portugal one) are often very intensive and very depending on the feed market. Dairy cows are permanently in stalls without litter (i.e. liquid manure). These characteristics are valid for almost all Mediterranean zones in plain.

- 100% liquid manure in pasture only areas

Dairy farms located in pasture areas are generally systems with 100% liquid manure. Furthermore, farms not growing cereals use also this system to not buy straw for litter. This is usually the case for Ireland, Scotland, West England, Wales, part of Denmark and Netherlands and most of North of Scandinavia.

- Solid manure in mixed farming areas

Since litter is often available in those farms, the manure is solid. This system is characteristic in North-West of France (Picardie, Nord Pas de Calais...), East of Netherlands and mixed farms in Denmark.

- Industrial farms issued from former Soviet collectivism (several hundreds cows)

These farms are still using no grazing at all leading to 100% liquid manure.

- Very small farms with less than 10 cows

Contrary to the previous ones, these farms are using litter for the animals which lead to 100% solid manure.

Table 3.3: Manure management characteristics of regions linked to BOMILK sector (From raw data provided by the CEMAGREF study on manure management.

Région		% des animaux sur déjections solides/ Liquides		% du temps passé en bâtiments				Echelle de validité des données
Code	Nom	% solide	% liquide	Hiver (Nov-Feb)	Printemps (Mars-Mai)	Eté (Juin-Aout)	Automne (Sep-Oct)	Nationale (N) ou Régionale (R)
AT31	Oberosterreich	60%	40%	90%	80%	50%	60%	N
AT33	Tyrol	60%	40%	90%	60%	10%	20%	R
AT33	Tyrol	60%	40%	90%	80%	50%	60%	N
AT33	Tyrol	60%	40%	100%	70%	50%	50%	nc
FI13	Ita-Suomi	nc	90%	90%	90%	10%	50%	nc
FI13	Ita-Suomi	40%	60%	100%	100%	10%	90%	N
FR25	Basse Normandie	90%	10%	100%	40%	100%	100%	R
FR25	Basse Normandie	60%	40%	100%	50%	0%	40%	R
FR30	Nord pas de calais	nc	nc	100%	50%	10%	30%	R
FR51	Pays de la loire	90%	10%	100%	30%	50%	0%	R
FR71	Rhone Alpes	30%	70%	100%	50%	0%	60%	R
DE40	Brandenburg	20%	80%	100%	90%	80%	90%	R
DEF0	Schkeswig-Holstein	20%	80%	100%	90%	80%	90%	R
IE01	Border, midland, and western	10%	100%	100%	20%	10%	20%	N
IE01	Border, midland, and western	10%	90%	70%	10%	0%	10%	nc
IE02	Southern and Eastern	10%	100%	100%	20%	10%	20%	N
IE02	Southern and Eastern	10%	90%	70%	10%	0%	10%	nc
ITC1	Piémont	60%	40%	nc	nc	nc	nc	N
ITC1	Piémont	80%	20%	100%	100%	100%	100%	R
ITC1	Piémont	50%	50%	100%	80%	70%	90%	R
ITC4	Lombardia	60%	40%	nc	nc	nc	nc	N
ITD5	Emilie Romagne	60%	40%	100%	70%	60%	70%	N
PL32	Podkarpackie	80%	20%	10%	10%	40%	40%	N
PL62	Warminsko-Mazurskie	80%	20%	10%	10%	40%	40%	N
PL63	Pomorskie	80%	20%	10%	10%	40%	40%	N
PT11	Norte-Portugal	10%	90%	100%	90%	100%	100%	R
PT11	Norte-Portugal	20%	80%	90%	90%	90%	90%	R
ES13	Cantabria	20%	80%	90%	50%	50%	60%	R
ES13	Cantabria	10%	90%	90%	40%	40%	60%	R
ES13	Cantabria	10%	100%	100%	90%	90%	90%	R
ES21	Pais Vasco	nc	nc	100%	90%	80%	90%	R
SE04	Suède (région inconnue)	30%	70%	10%	30%	80%	60%	R
CZ01	Praha	60%	40%	90%	90%	90%	90%	nc
CZ02	Stredni Cechy	60%	40%	90%	90%	90%	90%	nc
CZ03	Jihozapad	90%	10%	70%	60%	50%	50%	N
CZ06	Jihovychod	90%	10%	70%	60%	50%	50%	N
NL12	Friesland	0%	100%	100%	50%	70%	60%	N
NL12	Friesland	10%	90%	100%	20%	40%	20%	N
NL12	Friesland	10%	90%	100%	60%	20%	60%	R
NL12	Friesland	0%	100%	100%	30%	50%	30%	R
NL31	Utrecht	0%	100%	100%	50%	70%	60%	N
NL33	Zuid-Holland	0%	100%	100%	50%	70%	60%	N
NL33	Zuid-Holland	10%	90%	100%	20%	40%	20%	N
UKL	Wales	10%	90%	90%	60%	10%	40%	R
UKM	Scotland	10%	90%	100%	50%	20%	50%	R
UKM	Scotland	nc	90%	100%	50%	20%	50%	R
UKN	Northen Ireland	0%	100%	100%	20%	100%	80%	R

3.6. Conclusions

The aim of this study was to develop a regional zoning for the six main Livestock Production Systems in Europe and Norway: dairy cows (BOMILK), cattle rearing and fattening (BOMEAT), sheep and goats activities for milk as well for meat (SHGOAT), rearing and fattening of pigs (PROCIN), egg production (LAHENS) and meat production from broilers (POUFAT). These six livestock sectors were described from a set of variables extracted from the CAPRI Modelling System for the year 2002. The statistical classification of the livestock sectors allowed us to identify and suggest a set of LPS per livestock sector at regional level according to few livestock production dimensions:

- the feeding strategy
- the level of intensification of the production
- the keeping strategy
- the dependence on the market for feedstuffs supplies
- and the economic importance of a livestock sector

By having recourse to independent datasets such as Eurostat farm types or again JRC Agri4cast meteorological database and profile of animals’ assemblages, we have been able to cross-validate and propose effective descriptions of every one of the LPS identified. Then, by livestock sector, mapping of the main LPS identified has been done.

A better understanding of main manures management strategies was expected from an outsourced study to complete LPS typology for the development of the GGELS project. However, the small number of data collected did not allow us to use these results for improving the LPS typology or to provide relevant information for the quantification of GHG and NH_3 emissions with the CAPRI model (Chapter 6).

4. METHODOLOGY FOR QUANTIFICATION OF GREENHOUSE GAS AND AMMONIA EMISSIONS FROM THE LIVESTOCK SECTOR THE EU-27

Author: Franz Weiss; Contribution: Adrian Leip

4.1. Introduction

One of the pursued outputs of the project is an estimation of GHG emissions caused by animal products in the European Union on the NUTS2 regional scale. On the one hand results will be available in an activity based format, taking into account all emissions created during a specific agricultural production activity in the respective NUTS2 region. This information is particularly useful for the comparison with the official emission values of the national inventories, which consider only emissions directly created by activities inside the reporting countries. On the other hand, in order to get a more thorough idea of emissions created by livestock products, we need to consider also emissions created by the production of the inputs used. Moreover, the limits cannot be set at regional or national borders, since many inputs are imported. Therefore, a life cycle approach was implemented into CAPRI which considers emissions up to the farm gate (cradle-to-farm-gate), including emissions coming from the production of imported and regionally produced feedings. Quantification of GHG and NH_3 emission from livestock production for both approaches is done with the CAPRI model, which had a detailed GHG model already implemented. The CAPRI modelling system was developed in several research projects and by several research teams.

The individual emission sources considered are reported in Table 4.1 and will be discussed in detail in the subsequent sections. The table indicates also whether the emissions source is caused by livestock rearing systems or through the production of feed, as well as the economic sector these emissions are assigned to according to the IPCC classification. For methane, emissions from enteric fermentation and manure management are considered. For nitrogen emissions, manure management, manure deposited by grazing animals, application of manure and mineral fertilizers to agricultural soils, N delivery by crop residues, fertilizer production, and indirect emissions from volatilizing via NH_3 and NO_x or leaching and runoff during any of the before mentioned steps are taken into account. We quantify fluxes of reacitve nitrogen for the greenhouse gas N_2O, but also for NH_3 and NO_x. CO_2-emissions or $CO_{2\text{-eq}}$ will be calculated for mineral fertilizer production, on-farm energy use and feed transport. Finally, CO_2, N_2O and CH_4-emissions of land use changes induced by feed production are entering the process in the LCA.

Table 4.1: Emission sources to be reported by the GGELS project

Emission source	Livestock rearing	Feed production	IPCC sector	Gases
• Enteric fermentation	X		Agri	CH_4
• Livestock excretions				
o Manure management (housing and storage)	X		Agri	NH_3, N_2O, CH_4, NO_x
o Depositions by grazing animals	X		Agri	NH_3, N_2O, NO_x
o Manure application to agricultural soils	X		Agri	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		Agri	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	Ind (N_2O) Energy (CO_2)	CO_2, N_2O
o Use of fertilizers, direct emissions from agricultural soils and indirect emissions		X	Agri	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	Agri	N_2O
• Cultivation of organic soils		X	Agri (N_2O) LULUC (CO_2)	CO_2, N_2O
• Emissions from crop residues (including leguminous feed crops)		X	Agri	N_2O
• Feed transport (including imported feed)		X	Energy	$CO_{2\text{-eq}}$
• On-farm energy use (diesel fuel and other fuel electricity, indirect energy use by machinery and buildings)		X	Energy	$CO_{2\text{-eq}}$
• Pesticide use		X	Energy	
• Feed processing and feed transport		X	Energy	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 X	LULUC	CO_2,
o soil carbon stock change		X	LULUC	CO_2,
o biomass burning			LULUC	CH_4 and N_2O
• Emissions or removals from pastures, grassland and cropland	X	X	LULUC	CO_2

Agri: Agriculture; Ind: Industries; LULUC: Land use and land use change

The main strength of the CAPRI modelling system is the fact that it is based on a unified, complete and consistent data base, and integrates economic, physical and environmental information in a consistent way. The data used by the CAPRI modelling system are based on various sources like national statistics on slaughtering, herd size, crop production, land use, farm and market balance and foreign trade as well as regional statistics on the same issues from the REGIO database, if available. However, since frequently the various sources are not consistent with each other, data first have to pass a consistency check and, if necessary, they are modified by an automatic procedure, based on a "Highest Posterior Estimator" approach. So, in a first step a complete and consistent data base on member state level (COCO) is built, while in a second step regional data are adapted in order to be consistent with the national data of COCO. For a detailed description of the basic CAPRI-model see Britz (2008).

The basic module for the calculation of GHG-emissions was developed in the course of a PhD thesis (see Perez, 2006), strictly following the methodology recommended by the Intergovernmental Panel on Climate Change (see IPCC, 1996). CH_4-emissions are determined according to this approach, using updated parameters and emission factors (see IPCC, 2006), and applying an endogenous module for the calculation of digestibility values. During the MITERRA-EUROPE project (see Velthof et al., 2007) the calculation of nitrogen-emissions from agriculture was incorporated into CAPRI using a mass-preserving nitrogen flow approach, which is considered to be more precise and detailed than the IPCC default approach. Therefore, for the calculation of nitrogen emissions, like NH_3 and N_2O, the MITERRA-approach is applied. In the next step, direct and indirect CO_2-emissions from on-farm energy use have been introduced into the CAPRI system as an outcome of another PhD thesis (see Kraenzlein, 2008). Finally, in the current project the regional activity based emissions were implemented into a Life cycle approach (LCA), considering not only emissions created directly in agricultural production, but also emissions created by the production and the transport of inputs. In particular emissions from non-European feed production, including those of induced land use change, had to be introduced to the system.

However, it was not possible to calculate all emission sources considered in the present study with the standard CAPRI model, neither was is possible to obtain emission estimates on the basis of a life-cycle assessment. Thus, a significant part of the study was dedicated to extend the scope of the CAPRI model in order to satisfy the requirements of a comprehensive tool for calculating the carbon footprint of agricultural activities. The main additional modules which have been implemented to the CAPRI model[2] within GGELS, include (i) implementation 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 arable soils; and (v) emissions of feed transport. 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.

The new, updated version of CAPRI ("CAPRI-GGELS"[3]) is freely available, according to the general rules of the CAPRI-consortium[4].

In the following sections, as far as possible, all relevant formulas and parameters for the calculation of greenhouse gases in CAPRI-GGELS will be presented. However, due to the scope and complexity of the model the limit has to be set at the point of manure excretion in case of animal production and N-delivery to fields for animal feed production. For on-farm energy use a detailed description of used parameters would exceed the scope of this study and is, therefore, kept short. Section 4.2 will be devoted to the calculation of activity based emissions that are part of the agriculture sector as defined in the IPCC guidelines. The only exception are CO_2 emissions from the cultivation of organic soils, which are part of the land use, land use change, and forestry sector, but are described here together with N_2O emission from the cultivation of organic soils. All

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[2] CAPRI version, from 19/01/2010
[3] CAPRI-GGELS, (CAPRI-ECC branch), revision 5268 from 07/2010
[4] See the CAPRI-model homepage http://www.capri-model.org/

calculations are carried out for all NUTS2 regions of the European Union and result in emissions per hectare of land or per head of livestock. Methods to calculate emissions of inputs generated outside but used inside the agricultural sector which are required for the LCA calculations are explained in section 4.3. Some of those emissions have been calculated on the level of agricultural activities (section 4.3.1), others are calculated directly at a product level (section 4.3.2) such as feed transport and emissions from land use change.

Finally, section 4.4, explains how the activity based emissions were transformed to product based emissions, first for feed products and in a second step for animal products. The final results are emissions per unit of animal product, including all inputs employed for the production of the product up to the moment it leaves the farm (cradle to farm gate).

4.2. Activity-based GHG emissions from the European livestock system considered in the sector ‘agriculture’ of the IPCC guidelines

In this section the quantification of those emission sources is described which are also reported in the agriculture sector of the IPCC guidelines and, consequently, in the national inventories submitted annually by parties to the UNFCCC. These emission categories are:

- → CH_4 emissions from enteric fermentation (IPCC source category 4A)
- → CH_4 emissions from manure management (IPCC source category 4B(a))
- → N_2O emissions from manure management (IPCC source category 4B(b))
- → CH_4 emissions from rice cultivation (IPCC source category 4C)
- → N_2O emissions from agricultural soils (IPCC source category 4D)
- → CH_4 emissions from prescribed burning of savannas (IPCC source category 4E)
- → CH_4 emissions from field burning of agricultural residues (IPCC source category 4F)

Calculations of CH_4 emissions are described in section 4.2.1 and section 4.2.2. In this study we have not considered emissions from rice cultivation, as is not of relevance for livestock production systems, and emissions from field burning of agricultural residues, which is insignificant in Europe (around 0.1% of agricultural emissions, EEA 2010). Prescribed burning of savanna is not occurring in Europe.

N_2O emissions from agricultural soils are produced during the processes of nitrification and denitrification. Nitrification is the aerobic microbial oxidation of ammonium to nitrate, and denitrification is the anaerobic stepwise microbial reduction of nitrate to molecular nitrogen (N_2). Emissions from manure occur through both processes in the following stages:

- Directly, during housing and storage of manure (both dung and urine)
- Directly, in soils (with respect to direct deposition of grazing animals or intentional application of manure to agricultural land, from the application of mineral fertilizer and from crop residues).

- Indirectly, via the volatilisation of NH_3 and NO_x from manure during housing and storage and manure deposition on grassland and arable land, mineral fertilizers, and crop residues. Volatilized nitrogen is re-deposited at a later stage and partly converted to N_2O.

- Indirectly, after leaching and runoff of nitrogen during housing, storage, and deposition on grassland and arable land

CAPRI uses the approach of the MITERRA model that follows a mass-flow approach accounting for losses of nitrogen in earlier stages for the calculation of emissions in later stages. Therefore, all nitrogen fluxes must be considered, including those which are not contributing to greenhouse gas or NH_3 emissions. Direct emissions from manure (by deposition of grazing animals, housing, storage and application of manure) are described in section 4.2.3, while direct emissions from the application of mineral fertilizer and crop residues are described in the sections 4.2.4 and 4.2.5. Indirect emissions though volatilisation and leaching are described in the sections 4.2.6 and 4.2.7.

Finally, N_2O emissions from agricultural soils are also caused by the cultivation of organic soils, which is described in section 4.2.8. Since, apart from N_2O, the cultivation of organic soils releases also CO_2, which is considered an emission from the land use, land use change and forestry sector in the IPCC guidelines, we describe the calculation of both gases together for this emission source.

4.2.1. CH_4 emissions from enteric Fermentation

Enteric fermentation is a digestive process which, as a by product, produces methane. The rate of methane emissions in first line depends on the type of the digestive system and is much higher in the case of ruminant livestock (e.g. Cattle, Sheep, Goats, Buffalo and Camels) than in the case of Non-ruminant herbivores (Horses, Mules, Asses) or monogastric livestock (Swine and poultry). The *2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)* therefore recommend a more precise approach for the calculation of emissions (Tier 2 or Tier 3) of those ruminant species which play a major role in a country, while for all other species a simplified approach (Tier 1) is considered to be sufficient. The Tier 1 method uses default emission factors which are directly applied to the annual average livestock population. In contrast, the Tier 2 method requires the calculation of regional emission factors, which are derived from the gross energy intake.

The CAPRI-system applies a Tier 2 approach for dairy cows and cattle and a Tier 1 approach for all other animals. The calculation of Tier 2 emission factors is based on the approach suggested by the 2006 IPCC guidelines. Therefore, in a first step, net energy requirements for maintenance, activity, growth, lactation and pregnancy are calculated, while in a second step gross energy intake and emission factors are derived from those values. The calculation steps are shown in the subsequent formulas. If nothing else is mentioned in the text the values for the described variables are usually calculated for each of the above animal activities. This is not explicitly visualized in the expressions in order to reduce the number of subscripts.

$$(EF\,1)\quad NE_M = Cf_i * BW^{0.75}$$

$$(EF\,2)\quad NE_A = C_a * NE_M$$

$$(EF\,3)\quad NE_L = Milk * (1.47 + 0.4 * Fat) * \frac{305}{365}$$

$$(EF\,4)\quad NE_P = 0.1 * NE_M$$

$$(EF\,5)\quad NE_G = 22.02 * \left(\frac{BW}{C * MW}\right)^{0.75} * WG^{1.097}$$

$$(EF\,6)\quad GE = \left[\frac{\left(\frac{NE_M + NE_A + NE_L + NE_P}{REM}\right) + \left(\frac{NE_G}{REG}\right)}{\frac{DE\%}{100}}\right]$$

$$(EF\,7)\quad EF = \left[\frac{GE * \left(\frac{Y_M}{100}\right) * 365}{55.65}\right]$$

NE_M = net energy requirement for maintenance, MJ per day

NE_A = net energy requirement for animal activity, MJ per day

NE_L = net energy requirement for lactation, MJ per day

NE_P = net energy requirement for pregnancy, MJ per day

NE_G = net energy requirement for growth, MJ per day

GE = gross energy intake, MJ per day

Cf_i = 0.386 (dairy cows, suckling cows), 0.322 (calves, heifers), 0.37 (young bulls)

C_a = coefficient corresponding to animal's feeding situation; 0.00 (Stall), 0.17 (Pasture), 0.36 (Grazing large areas)

C = 0.8 (female calves, heifers), 1.0 (male calves), 1.2 (young bulls)

Milk = amount of milk produced, kg per day

Fat = Fat content of milk, % of weight

BW = average live body weight of the animals in the population, kg

MW = mature live body weight of an adult female in moderate body condition, kg

WG = average daily weight gain of the animals in the population, kg per day

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed

REG = ratio of net energy available in a diet for growth to digestible energy consumed

DE% = digestible energy expressed as a percentage of gross energy

EF = Emission factor, kg CH_4 per head and year

Y_M = methane conversion factor, percent of gross energy in feed converted to methane

The net energy requirement for maintenance (NE_M) is the amount of energy needed to keep the animal in equilibrium without gains or losses of body mass. For the average live weight (*BW*), 600 kg are assumed for dairy cows, 550 kg for suckling cows, and 425-450 kg (depending on the relative herd size of dairy and suckling cows) for heifers for rearing. For the fattening categories live weight is derived from the regional stocking density (livestock units per ha of grassland) and the regional production coefficient (kg beef per head), which comes from the CAPREG database. The net energy requirement for activity (NE_A) is the energy needed to obtain their food, water and shelter and is determined by the feeding situation, represented by the coefficient C_a. CAPRI uses country-specific estimates of time shares spent on pastures and in stable, taken from the RAINS database (see section 4.2.3.1 on N_2O emissions from grazing animals). For the time spent on large grazing areas no data are available. So, it is assumed to be zero. The net energy requirement for lactation (NE_L) is calculated by the daily milk production (*Milk*) and the fat content (*Fat*). The total milk production per head comes from the CAPREG database and is divided by an assumed lactation period of 305 days in order to get the daily milk production. For the fat content a default value of 4% is assumed. The net energy requirement for pregnancy (NE_P) is supposed to be 10% of the net energy requirement for maintenance, while the net energy requirement for growth (NE_G), the net energy required for the weight gain, depends on the daily weight increase and the live body weight of the animal in the population. The mature live body weight of an adult female in moderate body condition (*MW*) is a weighted average of the weight of suckling cows and dairy cows, while the daily weight gain (*WG*) depends on the age of the animals. In the case of calves for fattening it ranges between 0.8 kg/day and 1.2 kg/day, while calves for rearing gain 0.8 kg/day up to a weight of 150 kg and between 1kg/day and 1.4 kg/day from 151 kg to 335 kg (males) and 330 kg (females). The exact values in the range depend on the relation of the regional to the average EU stocking density. For young bulls daily weight gains range from 0.8 kg/day to 1.4 kg/day, depending on regional stocking densities and final weights, while heifers for fattening are assumed to gain 0.8 kg/day. The digestible energy as a percentage of gross energy (*DE%*) is calculated based on the feed intake using the methodology suggested by NRC (2001) (see text end of this section on digestibility). The methane conversion factor (Y_m) is supposed to be 6.5%. The ratio of net energy available to digestible energy consumed (*REM* and *REG*) is derived from *DE%*. For the exact calculation see the 2006 IPCC guidelines (IPCC, 2006: Vol.4, Eq.10.14 and 10.15).

For all other animals a Tier 1 approach was applied. As a first approximation the default emission factors of the *2006 IPCC Guidelines* (IPCC, 2006: Vol.4, Tab.10.10), 1.5 kg per head for pigs and 8 kg per head for sheep and goats[5], were used for all countries.

Digestibility

The feed digestibility (DE%) is the portion of the gross energy (GE) in the feed, which is not excreted in the faeces. Digestibility depends on the type of feed and, therefore, on the composition of feed given to the animals. While grain-based feeds reach a digestibility around 80% and more, pastures and forages show significantly lower values around 40-60%. As has been demonstrated in the previous section, a higher digestibility reduces the gross energy requirement and hence the methane emissions of enteric fermentation and manure management. In principle, feed digestibility influences also the methane conversion factor, again with high digestibility reducing the amount of methane produced, but the relationship is complex and can not be implemented in CAPRI. Since

[5] Since sheep and goats are not separated in CAPRI the emission factor for sheep was applied also to goats.

CAPRI internally calculates the feed composition the digestibility can be derived consistently for all bovine animal activities, where a Tier 2 approach is applied. The calculation is based on the method suggested by the National Research Council NRC (2001). The nutrient values of the feeds are, as far as available, taken directly from CAPRI and complemented by factors provided by NRC (2001) and Sauvant et al. (2004).

In a first step the truly digestible nutrients are derived from the standard nutrient contents for each feed. With 'truly digestible nutrients' we refer to NRC(2001). Both nutrient contents and truly digestible nutrients are given in percent of dry matter. From this we get the digestible energy (DE), which has to be corrected by a discount factor depending on the actual intake of the animal. The higher the actual intake compared to the maintenance requirements is, the lower is the digestible energy (see NRC, 2001). The discount factor, therefore, depends not only on the respective feed but also on the total feed received by the animal. Finally, the digestibility (DE%) for each animal activity is the weighted sum of the digestible energy divided by the gross energy (GE) over all feeds given to the animal. The exact calculation is demonstrated by the following equations:

$$(DG1) \quad TDNFC = 0.98 * [100 - (NDF - NDICP) - CP - EE - ASH] * PAF$$

$$(DG2) \quad TDCP^{Forages} = CP * e^{-1.2*\frac{ADICP}{CP}}$$

$$(DG3) \quad TDCP^{concentrates} = \left[1 - 0.4 * \frac{ADICP}{CP}\right] * CP$$

$$(DG4) \quad TDCP^{animal} = CP$$

$$(DG5) \quad TDFA = FA$$

$$(DG6) \quad TDNDF = 0.75 * (NDF - NDICP - L) * \left[1 - \left(\frac{L}{NDF - NDICP}\right)^{0.667}\right]$$

$$(DG7) \quad TDN = TDNFC + TDCP + TDFA * 2.25 + TDNDF - 7$$

$$(DG8) \quad ACTINT = \frac{NE_M + NE_A + NE_L + NE_P + NE_G}{NE_M} - 1$$

$$(DG9) \quad DISC = \frac{TDN - (0.18 * TDN - 10.3) * ACTINT}{TDN} \qquad for\ TDN > 60\%$$

$$(DG10) \quad DISC = 1 \qquad for\ TDN \leq 60\%$$

$$(DG11) \quad DE_{FEED} = \left[\frac{TDNFC + TDNDF}{100} * 4.2 + \frac{TDCP}{100} * 5.6 + \frac{FA}{100} * 9.4 - 0.3\right] * DISC$$

$$(DG12) \quad GE_{FEED} = \frac{100 - CP - FAT - ASH}{100} * 4.2 + \frac{CP}{100} * 5.6 + \frac{FAT}{100} * 9.4$$

$$(DG13) \quad DE\% = \frac{\sum_{feed} DE_{feed}}{\sum_{feed} GE_{feed}}$$

NDF = Neutral detergent fibre in percent of dry matter for each feed

ADF = Acid detergent fibre in percent of dry matter for each feed

LI = Acid detergent lignin in percent of dry matter for each feed

ASH = Dietary Ash in percent of dry matter for each feed

NDICP = Neutral detergent insoluble in percent of dry matter for each feed
ADICP = Acid detergent insoluble in percent of dry matter for each feed
CP = Crude protein in percent of dry matter for each feed
EE = Ether extract in percent of dry matter for each feed
FAT = Fat in percent of dry matter for each feed
PAF = Processing adjustment factor for each feed
TDNFC = Truly digestible non-fibre carbon hydrate in percent of dry matter for each feed
TDCP = Truly digestible crude protein in percent of dry matter for each feed
TDFA = Truly digestible fat in percent of dry matter for each feed
TDNDF = Truly digestible non detergent fibre in percent of dry matter for each feed
TDN = Total digestible nutrients in percent of dry matter for each feed
ACTINT = Actual energy intake related to net energy requirement for maintenance for each animal type
DISC = Discount factor for actual intake above maintenance level for each animal type
DE_{FEED} = Digestible energy at maintenance level in Mcal per kg for each feed and animal type
GE_{FEED} = gross energy Mcal per kg for each feed
DE% = digestible energy expressed as a percentage of gross energy for each animal type

4.2.2. CH_4 emissions from manure management

Methane is not only produced during digestion, but also during the treatment and storage of manure (dung and urine), when it is decomposed under anaerobic conditions. This is especially the case when large numbers of animals are managed in a confined area and the manure is treated as a liquid (e.g. in lagoons, tanks or pits). If treated as a solid or directly deposited on pastures manure decomposes under more aerobic conditions and less methane is produced. Therefore, beside the amount of manure produced, the methane emissions depend mainly on the system of storage and treatment of manure, the retention time in the storage facility and the temperature, which affects the process of decomposition.

For a good practice the *2006 IPCC Guidelines* recommend a Tier 2 or Tier 3 approach wherever possible, especially when an animal category plays an important role in a country. A simplified Tier 1 approach is only recommended for the case "if all possible avenues to use the Tier 2 method have been exhausted and/or it is determined that the source is not a key category or subcategory". While for the Tier 1 method information on the livestock population and average annual temperature combined with IPCC default emission factors is sufficient, a Tier 2 method additionally requires detailed information on manure management practices.

CAPRI applies a Tier 2 method for dairy cows and cattle and a Tier 1 approach for all other animal activities. The applied approaches (both Tier 1 and Tier 2) follow the methodology proposed in the *2006 IPCC Guidelines* (IPCC, 2006: Vol.4, Ch.10.4). In case of the Tier 2 approach, in addition, side effects of NH_3-emission reduction measures are considered. The calculation steps for the Tier 2 method are as follows:

$$(MM\ 1)\quad VS = GE * \left(1 - \frac{DE\%}{100} + UE\right) * \frac{1 - ASH}{GE_{FEED}} * 4.184$$

$$(MM\ 2)\quad EF = VS * 365 * B_0 * 0.67 * \sum_{s,k} MCF_{s,k} * MS_s * CLIM_k * \left(1 - \sum_a P_{s,a} * R_{s,a}^{CH_4} - \sum_b P_{s,b} * R_{s,b}^{CH_4}\right)$$

$$(MM\ 3)\quad \sum_s MS_s = 1$$

$$(MM\ 4)\quad \sum_k CLIM_k = 1$$

VS = Volatile solid excretion per day on a dry-organic matter basis, kg VS per day
GE = gross energy intake, MJ per day
DE% = digestible energy expressed as a percentage of gross energy
UE = urinary energy expressed as fraction of *GE*
ASH = ash content of manure as a fraction of dry matter feed intake
GE_{FEED} = gross energy Mcal per kg for each feed
EF = Emission factor, kg CH_4 per head and year intake
B_0 = maximum methane producing capacity for manure produced by the livestock category, m^3 CH_4 per kg *VS* excreted
$MCF_{s,k}$ = methane conversion factors for each manure management system s by climate region k, fraction
MS_s = fraction of manure handled using manure management system s
$CLIM_k$ = fraction of average temperature zone k in the region
$P_{s,a}$ = fraction of manure handled using housing system s with emission reduction measure a
$P_{s,b}$ = fraction of manure handled using storage system s with coverage type b
$R_{s,a}^{CH4}$ = factor of CH_4 emission reduction using housing system s with emission reduction measure a
$R_{s,b}^{CH4}$ = factor of CH_4 emission reduction using storage system s with coverage type b

The volatile solid excretion per day *(VS)* is the organic material in livestock manure and can be estimated from gross energy intake (*GE*) and digestible energy (*DE%*), which are also the main parameters for the calculation of the enteric fermentation emission factors (see section on enteric fermentation and digestibility). For the urinary energy fraction (*UE*) the IPCC default values of 0.04 (*UE*) is applied (IPCC, 2006: Vol.4, Eq.10.24), while the ash content (*ASH*) and the gross energy per kg of dry matter (GE_{FEED}) is calculated by CAPRI based on the feed diets (see section on digestibility). 4.184 is the conversion factor from Mcal to MJ, necessary since NRC (2001) calculates in Mcal, while IPCC uses MJ. The emission factors (*EF*) are then calculated in a second step. First, the volatile solid excretion (*VS*) is multiplied by the maximum methane producing capacity (B_0), which is converted from m^3/kg VS to kg/kg VS by the factor 0.67. For B_0 the IPCC default values for Western Europe (0.24 for dairy cows and 0.18 for other cattle; see IPCC, 2006: Vol.4, Table 10A-4 and 10A-5) are applied. The second term describes the fraction of the maximum methane producing capacity which is actually emitted with regard to the applied manure management systems and the climate region. $MCF_{s,k}$ is the fraction emitted by management system *s* in climate region *k*, which is multiplied by MS_s, the share of the management systems *s*, $CLIM_k$, the share of the average temperature zone *k* in the region and a factor derived from applied NH_3-emission reduction measures. Those values are then summarized over all management systems and average temperature zones. The sum of MS_s over all *s* and the sum of $CLIM_k$ over all *k* must be one, while the values of $MCF_{s,k}$ must be smaller than or equal to one. It is assumed, therefore, that all

management systems are equally distributed over the average temperature zones. CAPRI differentiates three manure management systems (Liquid, Solid and Pasture). Their shares on country level (MS_s) are coming from the RAINS database (http://gains.iiasa.ac.at) as the shares of NH_3-emission reduction measures ($P_{s,a}$ *and* $P_{s,b}$) and the effects of those measures on CH_4 emissions $R_{s,a}^{CH4}$ and $R_{s,b}^{CH4}$ (see also section on N_2O emissions from manure management). Average temperature zones are defined by the yearly average temperature based on one degree Celsius steps (from 10 degrees and lower to 20 degrees Celsius), as supposed by IPCC (2006). For each region the shares of manure produced in the different average temperature zones ($CLIM_k$) are derived from temperature and livestock data in the CAPRI database on the level of homogenous spatial mapping units (HSMUs) on the basis of the meteorological dataset derived by Orlandini and Leip (2008) and taking into consideration the livestock density distribution as estimated by Leip et al. (2008). For $MCF_{s,k}$ the IPCC default values for Western Europe are used (IPCC, 2006: 10.A-4 – 10A-5). They are shown in Table 4.2.

Table 4.2: Fractions of maximum methane producing capacity emitted by manure management systems (MCFs,k)

Management system	Fraction of maximum methane producing capacity emitted ($MCF_{s,k}$)										
	10°C and lower	11°C	12°C	13°C	14°C	15°C	16°C	17°C	18°C	19°C	20°C and above
Liquid/Slurry	0.10	0.11	0.13	0.14	0.15	0.17	0.18	0.20	0.22	0.24	0.26
Solid	0.02	0.02	0.02	0.02	0.02	0.04	0.04	0.04	0.04	0.04	0.04
Pasture	0.01	0.01	0.01	0.01	0.01	0.015	0.015	0.015	0.015	0.015	0.015

Sources: IPCC, 2006 (for liquid/slurry manure management systems a natural crust cover was assumed)

For swine, sheep, goats and poultry a simplified Tier 1 approach is applied, which does not require detailed information on management systems. It uses emission factors EF_k, which estimate emissions in kg per year and head of the average animal population according to the average temperature zones. CAPRI uses the IPCC default emission factors for Western Europe and Eastern Europe (IPCC, 2006: Tab. 10.14, 10.15, 10A-9), given in Table 4.3.

In combination with the above shares of average temperature zones in the EU countries ($CLIM_k$) the country specific Tier 1 emission factors are calculated in the following way:

$$(MM\ 5) \quad EF = \sum_k EF_k * CLIM_k$$

EF = Emission factor, kg CH_4 per head and year intake

$CLIM_k$ = fraction of the region in climate region k

EF_k = Tier 1 emission factors in climate region k

Table 4.3: CH_4 emission factors for manure management systems (Tier 1) in kg per head

		CH_4 emission factors										
		10°C and lower	11°C	12°C	13°C	14°C	15°C	16°C	17°C	18°C	19°C	20°C and above
Market Swine	Western Europe	6	6	7	7	8	9	9	10	11	11	12
	Eastern Europe	3	3	3	3	3	4	4	4	4	4	5
Breeding Swine	Western Europe	9	10	10	11	12	13	14	15	16	17	19
	Eastern Europe	4	5	5	5	5	6	7	7	7	8	8
Laying Hens		0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Poultry for fattening		0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Sheep and Goats		0.19	0.19	0.19	0.19	0.19	0.28	0.28	0.28	0.28	0.28	0.28

Sources: IPCC, 2006

4.2.3. Direct emissions of N_2O, NH_3, NO_x and N_2 from manure

The calculation of the N-cycle CAPRI, as far as possible, follows the methodology developed for the integrated nitrogen model MITERRA-EUROPE (Velthof et al., 2007), which does not only consider N_2O-emissions, but also the emissions of NH_3, NO_x, and N_2. The main data-source is the database of the RAINS-model (http://gains.iiasa.ac.at). An important note on the MITERRA-approach is that N_2O-emissions at a certain step of the N-cycle are not calculated on the basis of total initial N content of manure or mineral fertilizer, but on the remaining N applied at this step, after subtraction of losses of NH_3 and NO_x (and N_2) in earlier steps. Since, however, MITERRA so far uses IPCC emission factors, this approach is likely to underestimate emissions. Moreover, the effects of applied mitigation measures lead to a further reduction of the estimated emissions, compared to what would be the result of the IPCC default method. We therefore applied a correction to the default emission factors based on the default values of nitrogen volatilization given by the IPCC 2006 guidelines.

In the subsequent sections the approach and the relevant parameters will be presented for the single emission sources.

4.2.3.1 Direct emissions from deposition of grazing animals

This section considers all N_2O, NH_3 and NO_x emissions from manure (urine and dung) on pastures, ranges and paddocks, which result from grazing of animals. Therefore, manure deposited on pastures, ranges and paddocks by some kind of managed application is not included here, but in the section on application of manure.

The emissions are calculated in the following way:

$$(GR\ 1)\quad N_{MAN} = \frac{CRP_{IN}}{6} - RET_N$$

$$(GR\ 2)\quad S_{GRAZ} = \left(1 - \frac{Day_{ST}}{365}\right) * (1 - T_M)$$

$$(GR\ 3)\quad EF_{GRAZ}^{NH3} = N_{MAN} * S_{GRAZ} * LF_{GRAZ}^{NH3}$$

$$(GR\ 4)\quad EF_{GRAZ}^{NOx} = N_{MAN} * S_{GRAZ} * LF_{GRAZ}^{NOx}$$

$$(GR\ 5)\quad EF_{GRAZ}^{NO2} = N_{MAN} * S_{GRAZ} * \left(1 - LF_{GRAZ}^{NH3} - LF_{GRAZ}^{NOx}\right) * LF_{GRAZ}^{N2O} * \frac{44}{28}$$

CRP_{IN} = Crude protein intake, kg per head
RET_N = Export of N (retention), kg per head
S_{GRAZ} = Share of time per year for grazing
N_{MAN} = N in manure output at tail, kg per head
Day_{ST} = Number of days per year, that the animals normally spend in the stable
T_M = Share of time per day used for milking
EF_{GRAZ}^{NH3} = Emission factor for NH_3 during grazing, kg N per head
EF_{GRAZ}^{NOx} = Emission factor for NO_x during grazing, kg N per head
EF_{GRAZ}^{N2O} = Emission factor for N_2O during grazing, kg N_2O per head
LF_{GRAZ}^{NH3} = Share of N in manure deposited during grazing, volatilising as NH_3
LF_{GRAZ}^{NOx} = Share of N in manure deposited during grazing, volatilising as NO_x;
LF_{GRAZ}^{N2O} = Share of N in manure deposited during grazing, volatilising as N_2O

The N-content of animal excretion (N_{MAN}) is calculated by subtracting the exported N (or retention) in form of animal products from the intake in form of feed. First, the crude protein intake (CRP_{IN}) has to be transformed into its N-content by division by 6, then the retention (RET_N) is subtracted. The crude protein intake (CRP_{IN}) is derived from the same parameters as the net energy intake (*NE*), described in the section on methane emissions from enteric fermentation. So, among others, it depends on live body weight (*BW*), daily weight gain (*WG*), milk yield (*Milk*), fat content of milk (*Fat*) etc. The retention (RET_N) is based on the output coefficients, describing the relation between product outputs (milk) and animal activities (like dairy cows).

The emission factors for grazing, given in kg per head, are calculated by first multiplying the total animal excretion (N_{MAN}) with the share of manure, which is assumed to be deposited by animals during grazing. The days per year spent in the stable (Day_{ST}) and the assumed time for milking (T_M) is taken from the RAINS database. The values are country-specific and consistent with the pasture shares used for the calculation of methane emissions from manure management (MS_s). The data originate from a questionnaire collected in 2003 within the UNECE expert group on ammonia abatement. The results of this questionnaire are discussed in Klimont et al. (2005). Furthermore an exchange with national experts within the CAFE and NEC consultation processes and most recently under the Gothenburg revision process is reflected in the data. In cases of lacking responses, stable time was assumed to be half a year plus 20% of grazing time in house for milking during the

grazing period. Alternatively, the dataset of the national inventories is available, which, unfortunately, for some countries differs considerably. The deviations between official data used by the national inventories and RAINS data can be seen from Table 4.4.

Table 4.4: Shares of Manure fallen on pastures, ranges and paddocks during grazing (SGRAZ): Values of the RAINS database compared to National inventories and the IPCC default values

	Dairy cows			Other cows			Sheep and goats	
	RAINS	NI[2]	IPCC	RAINS	NI[2]	IPCC	RAINS	NI[2]
Belgium[1]	0.39	0.39	0.2	0.46	0.39	0.32	0.73	
Denmark	0.15	0.15	0.2	0.36	0.36	0.32	0.73	
Germany	0.07	0.15	0.2	0.14	0.14	0.32	0.72	
Greece	0.40	0.08	0.2	0.45	0.33	0.32	0.86	0.72-1.00
Spain	0.00	0.07-0.43	0.2	0.83	0.16-0.34	0.32	0.92	0.09-0.41
France	0.28	0.47	0.2	0.62	0.41	0.32	0.70	0.70
Ireland	0.56	0.57	0.2	0.61	0.65	0.32	0.82	0.92
Italy	0.10	0.01-0.04	0.2	0.05	0-0.02	0.32	0.90	0.25-0.65
Netherlands	0.36		0.2	0.36		0.32	0.73	
Austria	0.20	0.11	0.2	0.49	0.1	0.32	0.40	
Portugal	0.30	0.13-0.17	0.2	0.56	0.23-0.56	0.32	0.80	0.25-0.55
Sweden	0.21	0.23	0.2	0.45	0.41	0.32	0.50	
Finland	0.20	0.28	0.2	0.35		0.32	0.51	0.33
United Kingdom	0.38	0.46	0.2	0.50	0.51	0.32	0.96	0.98
Cyprus	0.39		0.2	0.45		0.32	0.86	
Czech Republic	0.36	0.08	0.2	0.30	0.33	0.32	0.73	0.87
Estonia	0.32	0.13	0.2	0.41	0	0.32	0.73	0.73-0.92
Hungary	0.39	0.08	0.2	0.49	0.15	0.32	0.66	0.4
Lithuania	0.40	0.4	0.2	0.45	0.2	0.32	0.73	0.73-0.92
Latvia	0.32	0.4	0.2	0.51	0.45	0.32	0.42	0.43
Malta	0.09		0.2	0.45		0.32	0.32	
Poland	0.19	0.12	0.2	0.19	0.1	0.32	0.73	0.10-0.50
Slovenia	0.12	0.12	0.2	0.15	0.12	0.32	0.64	0.46-0.68
Slovakia	0.40		0.2	0.45		0.32	0.73	
Bulgaria	0.40	0.13	0.2	0.45	0.22	0.32	0.73	
Romania	0.39	0.13	0.2	0.45	0.26	0.32	0.73	0.73-0.92

Sources: EEA, 2008, IPCC, 2006, own calculations; 1) Luxemburg included, 2) NI=National Inventories

In the second step the manure deposited during grazing is multiplied by the respective N-loss factors (LF_{GRAZ}) for N_2O, NH_3 and NO_x. For NH_3 a default loss factor of 8% for dairy cows and other cattle, and 4% for sheep and goats is assumed, for NO_x a general loss factor of 0.3%. For some countries country-specific factors were available and in accordance with the MITERRA model, applied. They are summarized in the following table:

Table 4.5: NH_3-Loss factors LF for grazing by animal categories and management systems (liquid, solid) in Percent

	NH_3				
	Dairy cows		Other cattle		Sheep Goats
	L[1]	S[1]	L[1]	S[1]	
Denmark	6.7	6.7	6.7	6.7	7
Germany	16.17	16.17	3.67	14.05	7.46
Spain	10	10	10	10	10
Ireland	5.2	5.2	1.2	1.2	3.9
Netherlands	7	7	7	7.5	5
Portugal	10	10	10	10	10
Finland	8	6	8	6	4
United Kingdom	5.2	5.2	1.5	1.5	6.3
Slovenia	5.5	5.5	5.5	5.5	5

Source: GAIN database; 1) L: Liquid, S: Solid

For N_2O, in contrast to the IPCC 2006 standard approach, the calculation is not based on the whole nitrogen deposition, but just on the share, which has not volatilised in form of NH_3 and NO_x. Therefore, the emissions of NH_3 and NO_x are first subtracted, before the loss factor of N_2O is applied. This corresponds to the general mass-flow approach of the MITERRA model. However, since the IPCC default loss factors (see IPCC, 2006: Vol.4, Tab.11.1) are used, which is 2% for dairy cows and cattle and 1% for sheep and goats, we first have to correct them by the IPCC default volatilisation as NH_3 and NO_x, which is 20% (see IPCC, 2006: Vol.4, Tab.11.3). This leads to actually applied N_2O -loss factors of 2.5% for dairy cows and cattle and 1.25% for sheep and goats. In order to get values in kg N_2O, we finally have to multiply the N-emissions by the correction factor 44/28.

Since, according to the definition of IPCC, a Tier 2 method would require country-specific emission factors the CAPRI approach for the calculation of N_2O emissions from grazing can be considered as a Tier 1 method.

4.2.3.2 Direct emissions from Manure Management

Direct emissions from manure management include all direct emissions of N_2O, NH_3 and NO_x, which are produced in stables and during storage and treatment of manure before it is applied to soils. Emissions from deposition on pastures, ranges and paddocks are not included here and have been discussed in the preceding section. Emissions from active application to soils will be the topic of the subsequent section.

According to the *IPCC guidelines,* N_2O emissions from manure management depend in first line on the type of manure management system in use. A method that uses the default emission factors of the IPCC guidelines (see IPCC, 2006: Vol.4, Tab.10.21) is considered as a Tier 1 approach, one which uses country specific values as Tier 2 approach. CAPRI follows the methodology of the MITERRA-EUROPE project, which differentiates between emissions from housing and from storage. The management systems are first divided into liquid and solid systems. Then for each system, according to the country specific estimate of the share of livestock, the assumed N-losses for the case without specific emission reduction measures are calculated. Finally, those basic

emissions are reduced according to country specific assumptions on applied emission reduction measures. Data on shares of manure management systems and mitigation measures come from the RAINS database. Mathematically the calculation can be described in the following way:

$$(MA\ 1)\quad S_{ST} = 1 - S_{GRAZ}$$

$$(MA\ 2)\quad EF_{HOUS}^{NH3} = N_{MAN} * S_{ST} * \sum_S MS_S * LF_{HOUS,S}^{NH3} * \left(1 - \sum_A P_{S,A} * R_{S,A}^{NH3}\right)$$

$$(MA\ 3)\quad EF_{HOUS}^{NOx} = N_{MAN} * S_{ST} * \sum_S MS_S * LF_{HOUS,S}^{NOx} * \left(1 - \sum_A P_{S,A} * R_{S,A}^{NOx}\right)$$

$$(MA\ 4)\quad EF_{HOUS}^{N2O} = \left(N_{MAN} * S_{ST} - EF_{HOUS}^{NH3} - EF_{HOUS}^{NOx}\right) * \sum_S MS_S * LF_{HOUS,S}^{N2O} * \left(1 - \sum_A P_{S,A} * R_{S,A}^{N2O}\right)$$

$$(MA\ 5)\quad EF_{STOR}^{NH3} = \left(N_{MAN} * S_{ST} - EF_{HOUS}^{NH3} - EF_{HOUS}^{NOx} - EF_{HOUS}^{N2O}\right) *$$

$$\sum_S MS_S * LF_{STOR,S}^{NH3} * \left(1 - \sum_B P_{S,B} * R_{S,B}^{NH3}\right) * (1 - C_S * 0.8)$$

$$(MA\ 6)\quad EF_{STOR}^{NOx} = \left(N_{MAN} * S_{ST} - EF_{HOUS}^{NH3} - EF_{HOUS}^{NOx} - EF_{HOUS}^{N2O}\right) *$$

$$\sum_S MS_S * LF_{STOR,S}^{NOx} * \left(1 - \sum_B P_{S,B} * R_{S,B}^{NOx}\right)$$

$$(MA\ 7)\quad EF_{STOR}^{N2} = \left(N_{MAN} * S_{ST} - EF_{HOUS}^{NH3} - EF_{HOUS}^{NOx} - EF_{HOUS}^{N2O} - EF_{STOR}^{NH3} - EF_{STOR}^{NOx}\right) *$$

$$\sum_S MS_S * LF_{STOR,S}^{N2} * \left(1 - \sum_B P_{S,B} * R_{S,B}^{N2}\right)$$

$$(MA\ 8)\quad EF_{MAN}^{NH3} = EF_{HOUS}^{NH3} + EF_{STOR}^{NH3}$$

$$(MA\ 9)\quad EF_{MAN}^{NOx} = EF_{HOUS}^{NOx} + EF_{STOR}^{NOx}$$

$$(MA\ 10)\quad EF_{MAN}^{N2O} = EF_{HOUS}^{N2O} * \frac{44}{28}$$

$$(MA\ 11)\quad \sum_S MS_S = 1$$

N_{MAN} = N in manure output at tail, kg per head
S_{ST} = Share of time per year the animal spends in the stable
S_{GRAZ} = Share of time per year for grazing
MS_s = fraction of manure handled using housing (storage) system s (s=liquid, solid)
$P_{S,A}$ = fraction of manure handled using housing system s with emission reduction measure A

$P_{S,B}$ = fraction of manure handled using storage system s with coverage types B

C_S = fraction of manure handled using storage systems with stable adaptation measures

$R_{S,A}^{NH3}$ = factor of NH_3 emission reduction using housing system s with emission reduction measure A

$R_{S,A}^{NOx}$ = factor of NO_x emission reduction using housing system s with emission reduction measure A

$R_{S,A}^{N2O}$ = factor of N_2O emission reduction using housing system s with emission reduction measure A

$R_{S,B}^{NH3}$ = factor of NH_3 emission reduction using storage system s with coverage type B

$R_{S,B}^{NOx}$ = factor of NO_x emission reduction using storage system s with coverage type B

$LF_{HOUS,S}^{NH3}$ = Share of N in manure deposited in housing system s (without reduction measures), lost as NH_3

$LF_{HOUS,S}^{NOx}$ = Share of N in manure deposited in housing system s (without reduction measures), lost as $NO_{x;}$

$LF_{HOUS,S}^{N2O}$ = Share of N in manure deposited in housing system s (without reduction measures), lost as N_2O

$LF_{STOR,S}^{NH3}$ = Share of N in manure deposited in storage system s (without reduction measures), lost as NH_3

$LF_{STOR,S}^{NOx}$ = Share of N in manure deposited in storage system s (without reduction measures), lost as $NO_{x;}$

$LF_{STOR,S}^{N2}$ = Share of N in manure deposited in storage system s (without reduction measures), lost as N_2

EF_{HOUS}^{NH3} = Emission factor for NH_3 during housing, kg N per head

EF_{HOUS}^{NOx} = Emission factor for NO_x during housing, kg N per head

EF_{HOUS}^{N2O} = Emission factor for N_2O during housing, kg N per head

EF_{STOR}^{NH3} = Emission factor for NH_3 during storage, kg N per head

EF_{STOR}^{NOx} = Emission factor for NO_x during storage, kg N per head

EF_{STOR}^{N2} = Emission factor for N_2 during storage, kg N per head

EF_{MAN}^{NH3} = Emission factor for NH_3 during housing and storage, kg N per head

EF_{MAN}^{NOx} = Emission factor for NO_x during housing and storage, kg N per head

EF_{MAN}^{N2O} = Emission factor for N_2O during housing and storage, kg N_2O per head

The N of manure entering the management systems is the share S_{ST} of total manure N_{MAN}, which is excreted inside the stable. Then, for each animal category, this is divided into manure in liquid and solid management systems by the shares MS_S . MS_S is shown in Table 4.6 and compared to those values reported by the member states in National Inventories (EAA, 2008). For sheep, goats and poultry no differentiation is applied. The RAINS values originate from the same questionnaire and revision process mentioned in section 4.2.3.1 (see Klimont et al., 2005).

Table 4.6: Shares of Manure management systems (MSs) for the calculation of N emissions during manure management (Comparison of values from RAINS and National Inventories)

	RAINS						National Inventories								
	Dairy cows		Other cows		Pigs		Dairy cows			Other cows			Pigs		
Country	Liq.	Solid	Liq.	Solid	Liq.	Solid	Liq.	Solid	Oth.	Liq.	Solid	Others	Liq.	Solid	Others
Belgium	0.48	0.52	0.36	0.64	0.93	0.07	0.50	0.50	0.00	0.50	0.50	0.00	1.00	0.00	0.00
Denmark	0.71	0.29	0.50	0.50	0.87	0.13	0.87	0.13	0.00	0.38	0.62	0.00	0.92	0.08	0.00
Germany	0.83	0.17	0.58	0.42	0.92	0.08	0.82	0.18	0.00	0.63	0.37	0.00	0.91	0.09	0.00
Greece	0.50	0.50	0.50	0.50	0.87	0.13	0.00	0.98	0.02	0.00	0.93	0.07	0.90	0.10	0.00
Spain	0.15	0.85	0.05	0.95	0.63	0.37	0.15	0.60	0.25	0.15	0.60	0.25	1.00	0.00	0.00
France	0.20	0.80	0.37	0.63	0.80	0.20	0.20	0.80	0.00	0.59	0.41	0.00	0.83	0.17	0.00
Ireland	0.93	0.07	0.72	0.28	1.00	0.00	0.94	0.06	0.00	0.67	0.33	0.00	1.00	0.00	0.00
Italy	0.36	0.64	0.36	0.64	1.00	0.00	0.40	0.60	0.00	0.57	0.43	0.00	1.00	0.00	0.00
Netherlands	1.00	0.00	0.94	0.06	1.00	0.00	n.a.	n.a.	1.00	n.a.	n.a.	1.00	n.a.	n.a.	1.00
Austria	0.30	0.70	0.30	0.70	0.80	0.20	0.21	0.79	0.00	0.27	0.73	0.00	0.71	0.29	0.00
Portugal	0.35	0.65	0.00	1.00	0.95	0.05	0.61	0.37	0.02	0.00	1.00	0.00	0.11	0.02	0.86
Sweden	0.57	0.43	0.30	0.70	0.79	0.21	0.58	0.42	0.00	0.26	0.45	0.29	0.70	0.26	0.05
Finland	0.45	0.55	0.25	0.75	0.57	0.43	0.52	0.48	0.00	0.00	0.00	1.00	0.60	0.40	0.00
UK	0.66	0.34	0.18	0.82	0.50	0.50	0.56	0.18	0.26	0.12	0.42	0.46	0.34	0.60	0.07
Cyprus	0.52	0.48	0.52	0.48	0.70	0.30	n.a.	n.a.	1.00	n.a.	n.a.	1.00	n.a.	n.a.	1.00
Czech Rep.	0.12	0.88	0.22	0.78	1.00	0.00	0.50	0.23	0.27	0.83	0.03	0.14	0.77	0.23	0.00
Estonia	0.18	0.82	0.42	0.58	0.73	0.27	0.22	0.77	0.01	0.42	0.57	0.01	0.29	0.00	0.71
Hungary	0.02	0.98	0.00	1.00	0.94	0.06	0.04	0.96	0.00	0.02	0.98	0.00	0.73	0.25	0.02
Lithuania	0.52	0.48	0.52	0.48	0.70	0.30	0.20	0.80	0.00	0.20	0.80	0.00	0.00	0.20	0.80
Latvia	0.05	0.95	0.03	0.97	0.47	0.53	0.06	0.89	0.05	0.04	0.93	0.04	0.46	0.51	0.03
Malta	0.00	1.00	0.00	1.00	1.00	0.00	n.a.	n.a.	1.00	n.a.	n.a.	1.00	n.a.	n.a.	1.00
Poland	0.20	0.80	0.25	0.75	0.30	0.70	0.08	0.92	0.00	0.17	0.83	0.00	0.29	0.71	0.00
Slovenia	0.55	0.45	0.55	0.45	0.77	0.23	0.55	0.45	0.00	0.55	0.45	0.00	0.56	0.36	0.08
Slovakia	0.52	0.48	0.52	0.48	0.70	0.30	n.a.	n.a.	1.00	n.a.	n.a.	1.00	n.a.	n.a.	1.00
Bulgaria	0.23	0.77	0.23	0.77	0.50	0.50	0.21	0.77	0.02	0.36	0.63	0.01	0.00	0.53	0.47
Romania	0.21	0.79	0.43	0.57	1.00	0.00	0.21	0.78	0.01	0.38	0.00	0.62	0.00	0.58	0.42

Sources: EEA, 2008

For each animal category, each management system *s* and both for housing and storage a loss factor *LF* for N losses in form of NH_3, NO_x, N_2 and N_2O is defined. This loss factor is the default value in case that no specific emission reduction measures are applied and defines the estimated upper limit of emissions of the country. For direct N_2O-emissions housing and storage are not explicitly differentiated and, therefore, there is only one loss factor applied (in the model at the stage of housing as can e seen from MA10). This loss factor is assumed to be 0.83/0.71% for dairy cows, 0.83/0.91% for other cattle and 0.96/0.91% for pigs, for liquid and solid systems respectively. This corresponds to the IPCC 2006 default value 0.5% (IPCC, 2006: Vol.4, Tab.10.21), corrected by the default values for volatilised NH_3 and NO_x (IPCC, 2006: Vol.4, Tab.10.22), assuming that liquid systems have a natural crust cover. For poultry, sheep and goats the values differ between old and new member states. In case of poultry the loss factor is assumed to be 0.77% for old, and 0.62% for new member states, for sheep and goats it is 0.83% for old and 0.57% for new member states respectively, derived from IPCC default values in the same way as for cattle and pigs.

Table 4.7: NH_3-Loss factors LF for housing and storage by animal categories and management systems (liquid, solid) in Percent

Country	Housing									Storage								
	Dairy cows		Other cattle		Swine		Sheep and goats	Lay. hens	Poultry for fattening	Dairy cows		Other cattle		Swine		Sheep and goats	Lay. hens	Poultry for fattening
	L[1]	S[1]	L[1]	S[1]	L[1]	S[1]				L[1]	S[1]	L[1]	S[1]	L[1]	S[1]			
Belgium	15.0	14.0	9.0	10.0	17.0	17.0	10.0	14.0	11.0	3.5	6.0	6.0	6.0	3.0	6.0	0.0	4.0	3.0
Denmark	8.0	7.0	8.0	7.0	17.0	18.0	15.0	25.0	20.0	6.0	7.0	6.0	7.0	5.0	6.0	6.0	7.0	12.8
Germany	7.3	7.3	9.8	8.5	16.5	13.1	11.4	20.0	20.8	6.2	3.7	9.4	9.1	7.9	8.6	5.9	3.4	3.7
Greece	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
Spain	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
France	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
Ireland	17.9	12.2	11.3	7.6	19.3	19.3	9.6	17.7	14.4	1.8	16.3	2.1	4.1	1.2	1.2	0.0	0.0	0.0
Italy	8.0	8.0	12.0	12.0	17.0	17.0	12.0	22.5	20.0	12.5	12.5	12.0	12.0	10.0	10.0	0.0	15.0	15.0
Netherlands	14.0	14.0	14.0	9.6	18.0	17.9	23.1	20.0	20.0	5.2	4.0	5.2	4.5	10.5	5.0	0.8	4.0	3.0
Austria	7.9	11.8	11.8	11.8	15.0	15.3	10.0	21.5	20.0	7.5	4.5	7.5	4.5	7.8	5.9	0.0	4.4	3.0
Portugal	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.1
Sweden	12.0	13.0	12.0	13.0	17.0	17.0	10.0	20.0	20.0	7.5	9.5	7.5	6.0	6.0	6.0	0.0	4.0	3.0
Finland	12.0	12.0	12.0	12.0	12.8	12.8	10.0	20.0	20.0	6.0	4.0	6.0	4.0	4.3	4.3	0.0	4.0	3.0
United Kingdom	18.9	13.7	18.9	13.7	20.2	15.7	13.0	26.2	6.3	5.6	6.6	5.6	6.6	8.6	13.6	13.6	9.6	6.8
Cyprus	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
Czech Rep.	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
Estonia	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
Hungary	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
Lithuania	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
Latvia	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
Malta	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
Poland	22.0	12.5	18.0	13.0	18.0	22.0	10.0	20.0	20.0	7.7	4.0	10.0	4.0	10.0	4.0	0.0	4.0	3.0
Slovenia	15.4	7.0	15.4	7.0	24.3	15.0	20.0	36.2	40.0	7.9	9.0	7.9	9.0	13.3	12.4	0.0	6.7	3.0
Slovakia	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
Bulgaria	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0
Romania	12.0	12.0	12.0	12.0	17.0	17.0	10.0	20.0	20.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	4.0	3.0

1) L: Liquid, S: Solid

For NO_x-emissions a general loss factor of 0.3% is applied for all animals, both for solid and liquid systems, once during housing and once during storage (so the total loss via NO_x during management is approximately 0.5-0.6%). N2-emissions do only occur during storage and are assumed to be 10% for solid and 1% for liquid systems. For poultry, sheep and goats the value for solid systems is applied. Loss factors for volatilisation via NH_3, in contrast to those of N_2O and NO_x, are country-specific and are presented in Table 4.7. Reasons for different loss factors are climatic differences, the type of housing and ventilation and the way housing and storage emissions are split (which in some cases led to adjustments to match nationally reported numbers). Moreover, storage under the building sometimes leads to reported emissions from storage of zero (since the latter is often defined as outside storage).

The emission reduction measures, which are considered in the MITERRA-EUROPE project, are mainly focusing on the reduction of NH_3-emissions, while other emissions may even be increased. For housing those are mainly measures for stable adaptation by improving design and construction of the floor, flushing the floor, climate control (for pigs and poultry) and wet and dry manure systems for poultry. In case of storage two options for manure coverage are considered, a low efficiency option with floating foils or polystyrene and a high efficiency option using tension caps, concrete, corrugated iron or polyester. Moreover, stable adaptation measures, unrelated to coverage, are taken into account for NH_3 (see Velthof et al., 2007). The assumed effects on emissions (1-*R*) are presented in Table 4.8.

Table 4.8: Effects of NH_3-Emission reduction measures for housing and storage on emissions of NH_3, NO_2, N2, NO_x and CH_4 (RS,A/B) by animal category and management systems (liquid, solid) in Percent

		Housing				Storage (manure coverage)				
		NH_3	N_2O	NO_x	CH_4	NH_3,		NO_x, N_2		CH_4
						High reduction	Low reduction	High reduction	Low reduction	
Dairy cows	Liquid	-25%	+/-0%	+/-0%	+/-0%	-80%	-40%	-80%	-40%	+10%
	Solid	-25%	+/-0%	+/-0%	+/-0%	-80%	+/-0%	-80%	-40%	+10%
Other cattle	Liquid	-25%	+/-0%	+/-0%	+/-0%	-80%	-40%	-80%	-40%	+10%
	Solid	-25%	+/-0%	+/-0%	+/-0%	-80%	+/-0%	-80%	-40%	+10%
Pigs	Liquid	-40%	+900%	+/-0%	-10%	-80%	-40%	-80%	-40%	+10%
	Solid	-40%	+900%	+/-0%	-10%	-80%	+/-0%	-80%	-40%	+10%
Laying hens		-65%	+900%	+/-0%	-90%	-80%	+/-0%	-80%	-40%	+10%
Other poultry		-85%	+900%	+/-0%	-90%	-80%	+/-0%	-80%	-40%	+10%

Source: GAINS database

The effects are assumed to be equal in all countries, except for NH_3-emission reductions in housing, where for Belgium and Netherlands other values are used (Netherlands: -50% for dairy cows, -40% for other cattle and -60% for other poultry; Belgium: -70% for other poultry). For stable adaptation measures in storage systems a reduction of NH_3-emission by 80% is assumed. The deviating numbers for Belgium and the Netherlands were recommended by Dutch and Belgium experts participating in the NEC/CAFe review and they are in relation to the emission factors used in GAINS.

The national shares of the NH_3-mitigation measures (*P*) are presented in the following tables. For housing, in general, just for a few countries mitigation measures are assumed to be present (see Table 4.9). This is due to the fact that only a few countries had a strict national legislation when the database was set up. Very recent developments are not yet considered. Coverage measures for storage are confined to liquid systems (see Table 4.10). For the shares of stable adaptation measures in storage systems (C_s) see Table 4.11. High shares are only assumed for the Netherlands since only in the Netherlands farms were obliged to cover manure storage (liquid) when the database was set up.

Table 4.9: Shares of NH_3-Emission reduction measures for housing (PS,A) by countries, animal categories and management systems (liquid, solid) in Percent

	Dairy cows				Other cows				Pigs				Laying hens		Other poultry	
	Liquid		Solid		Liquid		Solid		Liquid		Solid					
	Def	Red	Def	Red	Def	Red	Def	Red	Def	Red	Def	Red	Def	Red	Def	Red
Belgium	100	0	100	0	100	0	100	0	86	14	100	0	20	80	90	10
Denmark	95	5	100	0	100	0	100	0	72	28	100	0	100	0	100	0
Germany	100	0	100	0	100	0	100	0	85	15	100	0	100	0	100	0
Greece	100	0	100	0	100	0	100	0	95	5	100	0	95	5	90	10
Spain	100	0	100	0	100	0	100	0	90	10	100	0	80	20	95	5
France	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Ireland	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Italy	100	0	100	0	100	0	100	0	100	0	100	0	90	10	100	0
Netherlands	20	80	100	0	100	0	100	0	35	65	100	0	18	82	27	73
Austria	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Portugal	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Sweden	100	0	100	0	100	0	100	0	90	10	100	0	100	0	100	0
Finland	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
UK	100	0	100	0	100	0	100	0	100	0	100	0	75	25	100	0
Cyprus	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Czech Rep.	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Estonia	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Hungary	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Lithuania	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Latvia	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Malta	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Poland	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Slovenia	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Slovakia	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Bulgaria	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Romania	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0

Def: Default technology; Red: NH_3-emission reduction measures

Table 4.10: Shares of NH_3-Emission reduction measures for storage (due to manure coverage) (PS,B) by countries and animal categories in Percent

	Dairy cows (Liquid)			Other cows (Liquid)			Pigs (Liquid)			Other Poultry		
	Def	R H	R L	Def	R H	R L	Def	R H	R L	Def	R H	R L
Belgium	30	42.13	27.86	30	41.25	28.75	100	0	0	100	0	0
Denmark	7	93	0	5	95	0	40	60	0	100	0	0
Germany	78	20	2	78	20.7	1.3	100	0	0	100	0	0
Greece	100	0	0	100	0	0	100	0	0	100	0	0
Spain	100	0	0	100	0	0	100	0	0	100	0	0
France	88	2	10	94	2	4	77.65	5	17.35	100	0	0
Ireland	25	0	75	25	0	75	12.9	0	87.1	100	0	0
Italy	67	32	1	80	20	0	82	18	0	100	0	0
Netherlands	80	20	0	0	95	5	90	10	0	82	18	0
Austria	54.3	20	25.6	56.0	10	33.96	57.37	10	32.63	90	10	0
Portugal	100	0	0	100	0	0	100	0	0	100	0	0
Sweden	57	14	29	57	13.5	29.5	100	0	0	80	20	0
Finland	50	0	50	100	0	0	100	0	0	100	0	0
UK	20	0	80	20	0	80	100	0	0	100	0	0
Cyprus	100	0	0	100	0	0	100	0	0	100	0	0
Czech Rep.	100	0	0	100	0	0	100	0	0	100	0	0
Estonia	100	0	0	100	0	0	100	0	0	100	0	0
Hungary	100	0	0	100	0	0	100	0	0	100	0	0
Lithuania	100	0	0	100	0	0	100	0	0	100	0	0
Latvia	100	0	0	100	0	0	100	0	0	100	0	0
Malta	100	0	0	100	0	0	100	0	0	100	0	0
Poland	75	25	0	80	20	0	75	25	0	100	0	0
Slovenia	50	50	0	50	50	0	50.8	49.2	0	100	0	0
Slovakia	100	0	0	100	0	0	100	0	0	100	0	0
Bulgaria	100	0	0	100	0	0	100	0	0	100	0	0
Romania	100	0	0	100	0	0	100	0	0	100	0	0

Def: Default technology; RH: NH_3-emission reduction measures (strong reduction); RL: NH_3-emission reduction measures (low reduction)

Table 4.11: Shares of stable adaptation measures in storage systems by countries and animal categories (Cs) in Percent

	Dairy cows		Other cows		Pigs		Laying hens	Other poultry	Sheep and goats
Country	Liquid	Solid	Liquid	Solid	Liquid	Solid			
Belgium	0	0	0	0	14	0	80	10	0
Denmark	5	0	0	0	28	0	0	0	0
Germany	0	0	0	0	15	0	0	0	0
Greece	0	0	0	0	5	0	5	10	0
Spain	0	0	0	0	10	0	20	5	0
France	0	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0
Italy	0	0	0	0	0	0	10	0	0
Netherlands	80	0	0	0	65	0	82	73	0
Austria	0	0	0	0	0	0	0	0	0
Portugal	0	0	0	0	0	0	0	0	0
Sweden	0	0	0	0	10	0	0	0	0
Finland	0	0	0	0	0	0	0	0	0
UK	0	0	0	0	0	0	25	0	0
Cyprus	0	0	0	0	0	0	0	0	0
Czech Rep.	0	0	0	0	0	0	0	0	0
Estonia	0	0	0	0	0	0	0	0	0
Hungary	0	0	0	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0	0	0	0
Latvia	0	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0
Poland	0	0	0	0	0	0	0	0	0
Slovenia	0	0	0	0	0	0	0	0	0
Slovakia	0	0	0	0	0	0	0	0	0
Bulgaria	0	0	0	0	0	0	0	0	0

4.2.3.3 Direct emissions from manure application to agricultural soils

This section includes all emissions of NH_3, NO_x and N_2O, which are induced by the deposition of manure (dung and urine) on agricultural soils except for that part, which has already been considered in the section on grazing. So, direct emissions from application to agricultural soils can be manure deposited on arable land or pastures, however, not directly by the animal, but by farmers using application techniques. In the *2006 IPCC guidelines* those emissions are not considered in Chapter 10, like those from manure management, but in Chapter 11 (N_2O emissions from managed soils). IPCC differentiates between Tier 1 and Tier 2 approaches, which, however, are both based on the same calculation structure. The main difference is the use of country specific emission factors in Tier 2 approaches, while Tier 1 methods apply IPCC default values. According to the IPCC classification, the CAPRI approach can be regarded as a Tier 2 approach.

CAPRI calculates the emissions from application to soils based on total nitrogen in the manure output N_{MAN} reduced by the shares of nitrogen deposited during grazing, lost via volatilisation during manure management, lost via runoff during manure management and lost via surface-runoff after the application on soils (see section on indirect emissions from runoff and leaching). From the

remaining nitrogen in the manure, which is assumed to arrive at soil level, in a first step default emissions are calculated by multiplication with the default loss factor (*LF*). In a second step, the application of emission reduction techniques is supposed to reduce emissions by a certain degree (*R*) according to their country-specific frequency of usage (*P*). In contrast to the IPCC guidelines manure used for feed, fuel or construction is not considered in CAPRI. The emission factors are calculated according to the following formulas:

$$(AP\ 1)\quad EF_{AP}^{NH3} = \left(N_{MAN} * S_{ST} - EF_{MAN}^{NH3} - EF_{MAN}^{NOx} - EF_{HOUS}^{N2O} - EF_{STOR}^{N2} - N_{RUN}^{MAN} - N_{RUN}^{AP}\right) * \sum_S MS_S * LF_{AP,S}^{NH3} * \left(1 - \sum_C P_{S,C} * R_{S,C}^{NH3}\right)$$

$$(AP\ 2)\quad EF_{AP}^{NOx} = \left(N_{MAN} * S_{ST} - EF_{MAN}^{NH3} - EF_{MAN}^{NOx} - EF_{HOUS}^{N2O} - EF_{STOR}^{N2} - N_{RUN}^{MAN} - N_{RUN}^{AP}\right) * \sum_S MS_S * LF_{AP,S}^{NOx} * \left(1 - \sum_C P_{S,C} * R_{S,C}^{NOx}\right)$$

$$(AP\ 3)\quad EF_{AP}^{N2O} = \left(N_{MAN} * S_{ST} - EF_{MAN}^{NH3} - EF_{MAN}^{NOx} - EF_{HOUS}^{N2O} - EF_{STOR}^{N2} - N_{RUN}^{MAN} - N_{RUN}^{AP} - EF_{AP}^{NH3} - EF_{AP}^{NOx}\right) * \sum_S MS_S * LF_{AP,S}^{N2O} * \left(1 - \sum_C P_{S,C} * R_{S,C}^{N2O}\right) * \frac{44}{28}$$

N_{MAN} = N in manure output at tail, kg per head

S_{ST} = Share of time per year the animal spends in the stable

MS_s = fraction of manure handled using management system s (s=liquid, solid)

$P_{S,C}$ = fraction of manure handled using housing management system s with emission reduction measure C (application)

$R_{S,C}^{NH3}$ = factor of NH_3 emission reduction using management system s with emission reduction measure C (application)

$R_{S,C}^{NOx}$ = factor of NO_x emission reduction using management system s with emission reduction measure C (application)

$R_{S,C}^{N2O}$ = factor of N_2O emission reduction using management system s with emission reduction measure C (application)

$LF_{AP,S}^{NH3}$ = Share of N in manure deposited in management system s (without reduction measures), lost as NH_3

$LF_{AP,S}^{NOx}$ = Share of N in manure deposited in management system s (without reduction measures), lost as NO_x;

$LF_{AP,S}^{N2O}$ = Share of N in manure deposited in management system s (without reduction measures), lost as N_2O

EF_{HOUS}^{N2O} = Emission factor for N_2O during housing, kg N per head

EF_{STOR}^{N2} = Emission factor for N_2 during storage, kg N per head

EF_{MAN}^{NH3} = Emission factor for NH_3 during housing and storage, kg N per head

EF_{MAN}^{NOx} = Emission factor for NO_x during housing and storage, kg N per head

N_{RUN}^{MAN} = N lost via runoff during housing and storage, kg N per head

N_{RUN}^{AP} = N lost via surface runoff during application, kg N per head

EF_{AP}^{NH3} = Emission factor for NH_3 during application, kg N per head

EF_{AP}^{NOx} = Emission factor for NO_x during application, kg N per head

EF_{AP}^{N2O} = Emission factor for N_2O during application, kg N_2O per head

As in the case of manure management and grazing all used parameters and values come from the MITERRA-EUROPE project and, therefore, from the RAINS database. The loss factors (*LF*) for NO_x and N_2O are assumed to be unique for all member states and all management systems. For N_2O the IPCC default value of 1% (IPCC, 2006: Vol 4, Tab. 11.1) is corrected by the IPCC default volatilisation factor of 20% (IPCC, 2006: Vol 4, Tab. 11.3). This leads to an applied loss factor of 1.25%. For NO_x it is 0.03%, while for NH_3 country-specific values are applied which can be found in Table 4.12. The factors vary with climatic conditions, the application equipment, the season of the application and the manure properties of different animal categories.

Among NH_3-emission reduction measures during application high (immediate incorporation, deep and shallow injection of manure) and medium/low efficiency techniques (slit injection, trailing shoe, slurry dilution, band spreading and sprinkling) is distinguished (see Velthof et al., 2007). The emission reduction (*R*) is supposed to correspond to the values given in Table 4.13.

Table 4.12: NH_3-Loss factors LF for application by animal categories and management systems (liquid, solid) in Percent

	Dairy cows		Other cows		Pigs		Laying hens	Other poultry	Sheep and goats
Country	Liquid	Solid	Liquid	Solid	Liquid	Solid			
Belgium	28.0	8.0	28.0	8.0	30.0	10.0	34.0	6.0	10.0
Denmark	19.5	15.0	19.5	15.0	20.0	20.0	16.0	16.0	7.0
Germany	17.4	5.0	25.4	5.5	12.7	5.7	35.7	38.3	2.5
Greece	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Spain	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
France	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Ireland	23.7	8.0	27.0	7.8	8.5	8.5	15.5	9.7	5.0
Italy	22.5	22.5	24.0	24.0	25.0	25.0	23.0	16.0	22.0
Netherlands	34.0	13.6	34.0	13.6	40.8	17.0	30.6	30.6	32.1
Austria	30.0	15.5	30.0	15.5	16.3	13.6	20.0	20.0	10.0
Portugal	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Sweden	20.9	15.9	20.9	19.6	17.9	15.4	10.4	11.6	10.0
Finland	20.0	15.0	20.0	15.0	13.9	13.9	20.0	20.0	10.0
UK	22.5	8.1	20.0	8.9	16.4	24.3	35.9	35.9	10.5
Cyprus	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Czech Rep.	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Estonia	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Hungary	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Lithuania	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Latvia	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Malta	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Poland	20.0	16.0	20.0	16.0	23.0	20.0	20.0	20.0	10.0
Slovenia	24.3	22.9	24.3	22.9	28.2	19.1	23.3	25.0	20.0
Slovakia	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Bulgaria	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0
Romania	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	10.0

Table 4.13: Effects of NH_3-Emission reduction measures during application on emissions of NH_3, NO_2 and NO_x (RS,C) by animal category and management systems (liquid, solid) in Percent

		Medium/low efficiency measures			*High efficiency measures*		
		NH_3	No_x	N_2O	NH_3	No_x	N_2O
Dairy cows	Liquid	-40%	-40%	+60%	-80%	-80%	+100%
	Solid	-20%	-20%	+60%	-80%	-80%	+100%
Other cattle	Liquid	-40%	-40%	+60%	-80%	-80%	+100%
	Solid	-20%	-20%	+60%	-80%	-80%	+100%
Pigs	Liquid	-40%	-40%	+60%	-80%	-80%	+100%
	Solid	-20%	-20%	+60%	-80%	-80%	+100%
Laying hens		-20%	-20%	+60%	-80%	-80%	+100%
Other poultry		-20%	-20%	+60%	-80%	-80%	+100%
Sheep and goats		-20%	-20%	+60%	-80%	-80%	+100%

While for NH_3 and NO_x the measures lead to a reduction of emissions between 20% and 80%, N_2O-emissions increase by 60%-100%, depending on the type of measure applied. The values are assumed to be unique for all countries, except for some specific values in Belgium (NH_3-reductions of 50% in case of medium/low efficiency measures in liquid systems, and 70%/50% for high efficiency measures in liquid/solid systems). The presumed shares of emission reduction measures are presented in Table 4.14a and Table 4.14b. For the calculation of the runoff during housing and storage (N_{RUN}^{MAN}) and the surface runoff during application (N_{RUN}^{AP}) see the section on indirect emissions from runoff and leaching.

Table 4.14a: Shares of NH_3-Emission reduction measures during application (PS,C) by countries, animal categories (dairy cows and other cattle) and management systems (liquid, solid) in Percent

	Dairy cows						Other cattle					
	Liquid			Solid			Liquid			Solid		
	HE	LE	DEF	HE	LE	DEF	HE	LE	DEF	HE	LE	DEF
Belgium	12	41	47	0	66	34	9	41	50	0	63	37
Denmark	32	3	65	72	18	10	20	1	79	67	15	18
Germany	2	22	76	4	20	76	3	21	76	4	20	76
Greece	0	0	100	0	0	100	0	0	100	0	0	100
Spain	0	0	100	0	0	100	0	0	100	0	0	100
France	0	0	100	0	0	100	0	0	100	0	0	100
Ireland	0	0	100	0	0	100	0	0	100	0	0	100
Italy	20	10	70	10	30	60	19	1	80	5	15	80
Netherlands	50	50	0	0	80	20	40	40	20	0	80	20
Austria	0	10	90	5	5	90	0	10	90	5	5	90
Portugal	0	0	100	0	0	100	0	0	100	0	0	100
Sweden	8	7	85	20	15	65	8	7	85	20	15	65
Finland	2	47	51	0	47	53	2	47	51	0	47	53
UK	1	2	97	3	17	80	0	0	100	3	17	80
Cyprus	0	0	100	0	0	100	0	0	100	0	0	100
Czech Rep.	3	10	87	5	20	75	3	10	87	5	20	75
Estonia	0	0	100	0	0	100	0	0	100	0	0	100
Hungary	0	100	0	0	0	100	0	0	100	0	0	100
Lithuania	0	0	100	0	0	100	0	0	100	0	0	100
Latvia	0	0	100	0	0	100	0	0	100	0	0	100
Malta	0	0	100	0	0	100	0	0	100	0	0	100
Poland	0	0	100	5	95	0	0	0	100	5	95	0
Slovenia	0	20	80	0	20	80	0	20	80	0	20	80
Slovakia	0	0	100	0	0	100	0	0	100	0	0	100
Bulgaria	0	0	100	0	0	100	0	0	100	0	0	100
Romania	0	0	100	0	0	100	0	0	100	0	0	100

HE: Highly efficient emission reduction measures, LE: Medium/Low efficient emission reduction measures, DEF: No emission reduction measures

Table 4.14b: Shares of NH_3-Emission reduction measures during application (PS,C) by countries, animal categories (sine, poultry, sheep and goats) and management systems (liquid, solid) in Percent

	Swine						Laying hens			Other poultry			Sheep and goats		
	Liquid			Solid											
	HE	LE	DEF	HE	LE	DEF	HE	LE	DEF	HE	LE	DEF	HE	LE	DEF
Belgium	8	85	7	0	71	29	89	0	11	63	6	31	0	44	56
Denmark	28	0	72	72	18	10	64	18	18	67	15	18	64	18	18
Germany	14	51	35	16	54	30	99	1	0	30	70	0	0	0	100
Greece	5	0	95	0	0	100	5	0	95	10	0	90	0	0	100
Spain	9	1	90	0	0	100	20	0	80	5	0	95	0	0	100
France	12	10	79	0	0	100	0	0	100	0	0	100	0	0	100
Ireland	0	1	99	0	0	100	0	0	100	0	0	100	0	0	100
Italy	10	10	80	0	0	100	34	46	20	12	20	68	0	0	100
Netherlands	90	0	10	0	100	0	82	0	18	73	0	27	0	0	100
Austria	0	10	90	10	10	80	1	10	89	10	10	80	0	100	0
Portugal	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
Sweden	5	25	70	30	10	60	0	40	60	0	40	60	0	0	100
Finland	2	68	30	0	68	32	0	47	53	0	47	53	0	0	100
UK	14	0	87	20	0	80	18	36	46	11	23	65	0	0	100
Cyprus	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
Czech Rep.	5	20	75	0	0	100	0	0	100	0	0	100	0	0	100
Estonia	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
Hungary	0	100	0	0	0	100	0	0	100	0	0	100	0	0	100
Lithuania	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
Latvia	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
Malta	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
Poland	0	0	100	6	94	0	4	76	20	5	95	0	0	100	0
Slovenia	8	0	92	8	0	92	0	8	92	0	8	92	0	0	100
Slovakia	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
Bulgaria	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
Romania	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100

HE: Highly efficient emission reduction measures, LE: Medium/Low efficient emission reduction measures, DEF: No emission reduction measures

4.2.4. Direct emissions of N_2O, NH_3, and NO_x from the use of mineral fertilizers

This section includes all emissions of NH_3, NO_x and N_2O, which are induced by the deposition of mineral fertilizers on agricultural soils (including grassland). The calculation in CAPRI follows the approach of the MITERRA-EUROPE project, and, therefore, the methodology is similar as in proceeding section. Mineral fertilizers are differentiated by urea and other fertilizers. The calculation is based on the following formulas:

$$(MF\ 1)\quad EF_{MIN}^{NH3} = N_{MIN} * \sum_K FS_K * LF_{MIN,K}^{NH3}$$

$$(MF\ 2)\quad EF_{MIN}^{NOx} = N_{MIN} * \sum_K FS_K * LF_{MIN,K}^{NOx}$$

$$(MF\ 3)\quad EF_{MIN}^{N2O} = \left(N_{MIN} - EF_{MIN}^{NH3} - EF_{MIN}^{NOx}\right) * \sum_K FS_K * LF_{MIN,K}^{N2O} * \frac{44}{28}$$

N_{MIN} = N in chemical fertilizers applied to pastures and crops, kg per ha

FS_K = fraction of applied fertilizer type k (k=urea, other fertilizers) in total chemical fertilizer applied

$LF_{MIN,K}^{NH3}$ = Share of N in fertilizer type k, lost as NH_3

$LF_{MIN,K}^{NOx}$ = Share of N in fertilizer type k, lost as NO_x

$LF_{MIN,K}^{N2O}$ = Share of N in fertilizer type k, lost as N_2O

EF_{MIN}^{NH3} = Emission factor for NH_3 during application of chemical fertilizers on managed soils, kg N per ha

EF_{MIN}^{NOx} = Emission factor for NO_x during application of chemical fertilizers on managed soils, kg N per ha

EF_{MIN}^{N2O} = Emission factor for N_2O during application of chemical fertilizers on managed soils, kg N_2O per ha

The total amount of N applied as mineral fertilizers (N_{MIN}) is based on member state data of the European Fertilizer Manufacturer's Association as published by FAOSTAT and expert questionnaire data from EFMA reporting average mineral fertilizer application rates per crop and Member States (see IFA/IFDC/FAO, 2003), but the exact allocation to crops in CAPRI is done by an algorithm for input allocation. This algorithm estimates the most probable organic and inorganic rates which at the one hand exhaust the available organic and inorganic nutrient at Member State level, and on the other hand cover crop needs plus losses from ammonia emission (see Britz and Wizke, 2008; Leip et al., 2008; and Leip et al., 2010).

The applied N_2O-loss factor (*LF*) corresponds to the default emission factor of 1%, recommended in the 2006 IPCC guidelines (IPCC, 2006: Vol.4, Tab.11.1) corrected for the IPCC default volatilisation of 10% (IPCC, 2006: Vol.4, Tab.11.3). This leads to an applied loss factor of 1.11%, while the national inventories use the old emission factor of 1.25%. The CAPRI-loss factors for NH_3+NO_x, those used in the National inventories, and the assumed fractions of applied fertilizer types from RAINS (urea and other fertilizers) are presented in Table 4.15. Differences in the loss factors are due to climatic conditions, soil moisture, soil type and in the category "other" different shares of fertilizer types leading to different weighted emission factors. For details on the RAINS-data see Klimont (2005).

Table 4.15: Shares of fertilizer type (urea, other fertilizers) use and NH_3+NO_x-loss factors in CAPRI compared to those reported by the member states (National Inventories of 2007 for 2002) in Percent

	CAPRI							***NI[1]***
	Shares of fertilizer types		NH_3-loss factors		NH_3+NO_x loss factors			
	Urea	Others	Urea	Others	Urea	Others	Total	Total
Belgium	1	99	15.0	1.9	15.3	2.2	2.33	4.3
Denmark	1	99	15.0	2.1	15.3	2.4	2.57	2.2
Germany	16	84	15.0	1.5	15.3	1.8	3.96	4.7
Greece	2	98	20.0	3.7	20.3	4.0	4.33	10.0
Spain	26	74	16.0	4.4	16.3	4.7	7.72	6.3
France	10	90	15.0	3.7	15.3	4.0	5.10	10.0
Ireland	14	86	18.1	2.4	18.4	2.7	4.92	1.7
Italy	44	56	15.0	3.2	15.3	3.5	8.69	9.0
Netherlands	0	100	15.0	2.3	15.3	2.6	2.62	n.a.
Austria	3	97	15.0	2.0	15.3	2.3	2.69	2.7
Portugal	18	82	15.0	3.1	15.3	3.4	5.57	5.7
Sweden	0	100	15.0	0.7	15.3	1.0	1.03	1.4
Finland	1	99	15.0	0.8	15.3	1.1	1.19	0.6
United Kingdom	7	93	15.0	1.7	15.3	2.0	2.88	10.0
Cyprus	8	92	15.0	3.3	15.3	3.6	4.54	10.0
Czech Republic	12	88	15.0	3.3	15.3	3.6	5.00	10.0
Estonia	4	96	15.0	2.1	15.3	2.4	2.92	10.0
Hungary	12	88	15.0	2.5	15.3	2.8	4.30	10.0
Lithuania	0	100	15.0	6.6	15.3	6.9	6.90	10.0
Latvia	32	68	15.0	2.0	15.3	2.3	6.46	10.0
Malta	0	100	15.0	2.5	15.3	2.8	2.77	n.a.
Poland	25	75	15.0	4.4	15.3	4.7	7.36	10.0
Slovenia	15	85	15.0	2.0	15.3	2.3	4.25	10.0
Slovakia	16	84	15.0	2.0	15.3	2.3	4.38	10.0
Bulgaria	11	89	15.0	2.8	15.3	3.1	4.46	10.0
Romania	34	66	15.0	2.8	15.3	3.1	7.26	10.0

Sources: EEA, 2008, own calculations; 1) NI=National Inventories

4.2.5. Direct emissions from crop residues, including N-fixing crops

Crop residues, if left on the field, serve as a supplier of nutrients, like manure or chemical fertilizers, and are, therefore, sources of N-emissions. Similarly, biological nitrogen fixation increases the amount of N available for plant nutrition and emissions. With respect to the IPCC Guidelines 1996, on the one hand, the calculation of emissions from crop residues has changed, so that now it also accounts for the contribution of the below-ground nitrogen, which previously had been ignored. On the other hand biological nitrogen fixation has been removed as a direct source of N_2O-emissions due to a lack of evidence of significant emissions arising from the fixation process itself. In contrast to manure and chemical fertilizers, CAPRI, in accordance with the IPCC guidelines, calculates direct N_2O-emissions and indirect emissions from leaching, but not indirect emissions of NH_3 and NO_x for N of crop residues. CAPRI estimates the emissions according to the following formulas:

$$(CR\ 1)\quad N_{CR} = N_{PLANT} * F_{CR}$$

$$(CR\ 2)\quad EF_{CR}^{N2O} = N_{CR} * (1 - CRBU - CRFU - CRFE) * LF_{CR}^{N2O} * \frac{44}{28}$$

N_{CR} = N delivery from crop residues, kg per ha

N_{PLANT} = N uptake of the plant (harvested product + residues), kg N per ha

F_{CR} = relation of N in crop residues to N uptake by plants (crop specific)

$CRBU$ = share of crop residues burned on the field

$CRFU$ = share of crop residues used as fuel

$CRFE$ = share of crop residues used as animal feed

LF_{CR}^{N2O} = Share of N of crop residues, lost as N_2O

EF_{CR}^{N2O} = Emission factor for N_2O for N from crop residues, kg N_2O per ha

The delivery of N (N_{CR}) is calculated for each crop by the multiplication of the N uptake of the grown pants (N_{PLANT}) with a crop-specific factor (F_{CR}). N_{PLANT} depends on the country-specific yield, while the factor F_{CR} describes the assumed relation of N in crop residues to the N uptake by the whole plant. F_{CR} is assumed to be crop specific but not country specific. The shares of crop residues, which are burned at the field (*CRBU*) or used as fuel (*CRFU*) or feed (*CRFE*) do not contribute to N delivery and are therefore subtracted. Due to a lack of available information, *CRFU* and *CRFE* are currently assumed to be zero. *CRBU* is supposed to be 10% for Greece, Spain, Italy, Portugal and the new member states, while the other countries are not supposed to practise the burning of crop residues. The applied loss factor (*LF*) corresponds to the value of 1%, recommended in the IPCC 2006 guidelines (IPCC, 2006: Vol.4, Tab.11.1).

4.2.6. Indirect N_2O-emissions following N-deposition of volatilized NH_3/NO_x

N_2O-emissions do not only occur through a direct but also through indirect pathways. One of them is the volatilisation of N as NH_3 and NO_x and the succeeding deposition as ammonium and nitrate onto soils. Arrived there they increase the total amount of deposited N and, therefore, participate in the same processes (nitrification, denitrification) as directly deposited fertilizers. The fraction that volatilizes as NH_3 and NO_x is explicitly calculated in CAPRI at the different steps of the N-cycle. The applied loss factors are presented in the respective sections. N_2O -emissions are then derived from the total of those emissions.

From the N that volatilizes as NH_3 and NO_x and is deposited again on soils or water surfaces a certain share (LF_{IN}^{N2O}) volatilizes as N_2O. This share is assumed to be 1% in CAPRI, which corresponds to the IPCC 2006 default value (see IPCC, 2006: Vol.4, Tab.11.3). Formally, the calculation is based on the following formula:

$$(AM\ 1)\quad EF_{IN}^{N2O} = \left(EF_{GRAZ}^{NH3} + EF_{GRAZ}^{NOx} + EF_{MAN}^{NH3} + EF_{MAN}^{NOx} + EF_{AP}^{NH3} + EF_{AP}^{NOx} + EF_{MIN}^{NH3} + EF_{MIN}^{NOx}\right) * LF_{IN}^{N2O} * \frac{44}{28}$$

LF_{IN}^{N2O} = Share of N volatilizing as NH_3 or NO_x lost as N_2O

EF_{GRAZ}^{NH3} = Emission factor for NH_3 during grazing, kg N per head

EF_{GRAZ}^{NOx} = Emission factor for NO_x during grazing, kg N per head

EF_{MAN}^{NH3} = Emission factor for NH_3 during housing and storage, kg N per head

EF_{MAN}^{NOx} = Emission factor for NO_x during housing and storage, kg N per head

EF_{AP}^{NH3} = Emission factor for NH_3 during manure application on managed soils, kg N per head

EF_{AP}^{NOx} = Emission factor for NO_x during manure application on managed soils, kg N per head

EF_{MIN}^{NH3} = Emission factor for NH_3 during application of chemical fertilizers on managed soils, kg N per ha

EF_{MIN}^{NOx} = Emission factor for NO_x during application of chemical fertilizers on managed soils, kg N per ha

EF_{IN}^{N2O} = Emission factor for indirect N_2O from N manure volatilizing as NH_3 or NO_x, kg N_2O per head/ha

4.2.7. Indirect N_2O-emissions following from Leaching and Runoff

Beside losses in gaseous form N is lost in form of leaching and runoff, predominantly as nitrate. Leaching is the flow below the soil rooting depth to the groundwater system, while runoff is the superficial flow into surface waters such as lakes and rivers. Some parts of N lost via leaching and runoff is transformed into N_2O, and, therefore, have to be considered in the N_2O-emissions. Sources of N leaching and runoff, which are relevant for the sake of this study, are the deposition of manure by grazing animals, the treatment of manure during housing and storage, the application of manure upon managed soils, the application of mineral fertilizers and the N delivered by crop residues.

The calculation in CAPRI is carried out in the following steps. First, the leaching fraction from manure management (N_{RUN}^{MAN}) is figured out after the calculation of gaseous emissions from housing and storage, and then the superficial runoff during the application of manure on managed soils (N_{RUN}^{AP}) is derived. The latter is added to the superficial runoff of manure deposited by grazing animals. After those steps the gaseous emissions from manure application upon managed soils are estimated (see section on manure application on managed soils). The superficial runoff from the application of mineral fertilizers (N_{RUN}^{MIN}) is determined in the same way, using the same loss factor (LF_{RUN}) as for grazing and manure application. The leaching below soils (N_{LEA}) is derived from the N surplus, which is the total of all N delivered to the agricultural system (NT_{MIN}, NT_{MAN}, NT_{FIX}, NT_{CR}, NT_{ATD}) minus the total of N leaving the agricultural system in form of animal and crop products (NT_{EXP}), gaseous emissions ($NT_{GAS}^{GRAZ+MAN+AP}$, NT_{GAS}^{MIN}), superficial runoff or leaching during manure management ($NT_{RUN}^{GRAZ+MAN+AP}$, NT_{RUN}^{MIN}). The gaseous N_2O-emissions from leaching and runoff are then estimated by the multiplication of N lost by superficial runoff, leaching during manure management and leaching below soils with a unique loss factor ($LF_{LEA+RUN}^{N2O}$). The exact calculation corresponds to the following formulas:

$$(LE\ 1)\quad N_{RUN}^{GRAZ} = \left(N_{MAN} * S_{GRAZ} - EF_{GRAZ}^{NH3} - EF_{GRAZ}^{NOx} - EF_{GRAZ}^{N2O} * \frac{28}{44} \right) * LF_{RUN}$$

$$(LE\ 2)\quad N_{RUN}^{MAN} = \left(N_{MAN} * S_{ST} - EF_{MAN}^{NH3} - EF_{MAN}^{NOx} - EF_{HOUS}^{N2O} - EF_{STOR}^{N2} \right) * \sum_{S} MS_{S} * NVZ * \left[LF_{RUN,S,Bas}^{MAN} * (1 - P_{ND}) + LF_{RUN,S,ND}^{MAN} * P_{ND} \right]$$

$$(LE\ 3)\quad N_{RUN}^{AP} = \left(N_{MAN} * S_{ST} - EF_{MAN}^{NH3} - EF_{MAN}^{NOx} - EF_{HOUS}^{N2O} - EF_{STOR}^{N2} - N_{RUN}^{MAN} \right) * LF_{RUN}$$

$$(LE\ 4)\quad N_{RUN}^{MIN} = \left(N_{MIN} - EF_{MIN}^{NH3} - EF_{MIN}^{NOx} - EF_{MIN}^{N2O} * \frac{28}{44} \right) * LF_{RUN}$$

$$(LE\ 5)\quad NT_{RUN}^{GRAZ+MAN+AP} = \sum_{hd,sp} \left(N_{RUN}^{GRAZ} + N_{RUN}^{MAN} + N_{RUN}^{AP} \right) * LEVL$$

$$(LE\ 6)\quad NT_{RUN}^{MIN} = \sum_{ha,cp} N_{RUN}^{MIN} * LEVL$$

$$(LE\ 7)\quad NT_{GAS}^{MIN} = \sum_{ha,cp} \left(EF_{MIN}^{NH3} + EF_{MIN}^{NOx} + EF_{MIN}^{N2O} * \frac{28}{44} \right) * LEVL$$

$$(LE\ 8)\quad NT_{GAS}^{GRAZ+MAN+AP} = \sum_{hd,sp} \left[\begin{array}{l} EF_{GRAZ}^{NH3} + EF_{GRAZ}^{NOx} + EF_{MAN}^{NH3} + EF_{MAN}^{NOx} + EF_{HOUS}^{N2O} + EF_{STOR}^{N2} \\ + EF_{AP}^{NH3} + EF_{AP}^{NOx} + \left(EF_{AP}^{N2O} + EF_{GRAZ}^{N2O} \right) * \frac{28}{44} \end{array} \right] * LEVL$$

$$(LE\ 9)\quad NT^{MAN} = \sum_{ha,cp} N^{MAN} * LEVL$$

$$(LE\ 10)\quad NT_{MAN} = \sum_{hd,sp} N_{MAN} * LEVL$$

$$(LE\ 11)\quad NT_{CAT} = \sum_{ha,cp} N_{CAT} * LEVL \quad for \quad CAT \in \{MIN, FIX, CR, ATD\}$$

$$(LE\ 12)\quad NT_{LEA} = \left(\begin{array}{l} NT_{MAN} + NT_{MIN} + NT_{ATD} + NT_{FIX} + NT_{CR} - \\ NT_{EXP} - NT_{RUN}^{MIN} - NT_{RUN}^{GRAZ+MAN+AP} - NT_{GAS}^{MIN} - NT_{GAS}^{GRAZ+MAN+AP} \end{array} \right) * LF_{LEA}$$

$$(LE\ 13)\quad EPR = \frac{NT_{EXP}}{NT_{MAN} + NT_{MIN} + NT_{ATD} + NT_{FIX} + NT_{CR}}$$

$$(LE\ 14)\quad NT_{LEA}^{GRAZ+AP} = \sum_{hd,sp} \left[\begin{array}{l} N_{MAN} * (1 - EPR) - EF_{GRAZ}^{NH3} - EF_{GRAZ}^{NOx} - EF_{MAN}^{NH3} - EF_{MAN}^{NOx} - EF_{HOUS}^{N2O} - EF_{STOR}^{N2} \\ - EF_{AP}^{NH3} - EF_{AP}^{NOx} - \left(EF_{AP}^{N2O} + EF_{GRAZ}^{N2O} \right) * \frac{28}{44} - N_{RUN}^{GRAZ} - N_{RUN}^{MAN} - N_{RUN}^{AP} \end{array} \right] * LEVL$$

$$(LE\ 15)\quad N_{LEA}^{MIN} = \left(N_{MIN} * (1 - EPR) - EF_{MIN}^{NH3} - EF_{MIN}^{NOx} - EF_{MIN}^{N2O} * \frac{28}{44} - N_{RUN}^{MIN} \right) * LF_{LEA}$$

$$(LE\ 16)\quad N_{LEA}^{FIX+CR+ATD} = \left(N_{CR} + N_{FIX} + N_{ATD} \right) * (1 - EPR) * LF_{LEA}$$

$$(LE\ 17)\quad EF(1)_{LEA+RUN}^{N2O} = \left(N_{RUN}^{MIN} + N_{LEA}^{MIN} + N_{LEA}^{FIX+CR+ATD} + \frac{NT_{RUN}^{GRAZ} + NT_{RUN}^{AP} + NT_{LEA}^{GRAZ+AP}}{NT^{MAN}} * N^{MAN} \right) * LF_{LEA+RUN}^{N2O} * \frac{44}{28}$$

$$(LE\ 18)\quad EF(2)_{LEA+RUN}^{N2O} = NT_{RUN}^{MAN} * LF_{LEA+RUN}^{N2O} * \frac{44}{28}$$

N_{MAN} = N in manure output at tail, kg per head

N_{MIN} = N in chemical fertilizers applied to pastures and crops, kg per ha

N_{CR} = N delivery from crop residues, kg per ha

N_{FIX} = N delivery from biological fixation, kg per ha
N_{ATD} = N delivery from atmospheric deposition, kg per ha
S_{GRAZ} = Share of time per year for grazing
S_{ST} = Share of time per year the animal spends in the stable
MS_s = fraction of manure handled using housing (storage) system s (s=liquid, solid)
NVZ = Share of region being a Nitrate Vulnerable Zone (NVZ)
$LEVL$ = number of heads or hectares of a certain animal species or crop in a region
N^{MAN} = N from manure deposited on fields or pastures (crop specific), kg N per ha
N_{RUN}^{GRAZ} = Surface runoff of N manure deposited by grazing animals, kg N per head
N_{RUN}^{MAN} = N manure leaching during housing and storage, kg N per head
N_{RUN}^{AP} = N manure superficial runoff during application upon managed soils, kg N per head
N_{RUN}^{MIN} = N surface runoff from application of mineral fertilizers, kg N per ha
N_{LEA}^{MIN} = N leaching below soil from application of mineral fertilizers, kg N per ha
$N_{LEA}^{FIX+CR+ATD}$ = N leaching below soil from N delivery of crop residues, biological fixation and atmospheric deposition, kg N per ha
NT_{MAN} = Total N from manure excreted by animals (sum over all animal species sp and heads hd), kg N
NT_{MIN} = Total N from chemical fertilizers (sum over all crops cp and crop areas ha), kg N
NT_{FIX} = Total N from biological fixation (sum over all crops cp and crop areas ha), kg N
NT_{ATD} = Total N from atmospheric deposition (sum over all crops cp and crop areas ha), kg N
NT_{CR} = Total N from crop residues (sum over all crops cp and crop areas ha), kg N
NT_{EXP} = Total N retention in crop products, crop residues and animals
NT^{MAN} = Total N from manure deposited on fields or pastures (sum over all crops cp and crop areas ha), kg N
NT_{RUN}^{MIN} = Total losses of organic N from chemical fertilizers (sum over all crops cp and crop areas ha) by superficial runoff, in kg N
$NT_{RUN}^{GRAZ+MAN+AP}$ = Total losses of organic N (sum over all animal species sp and heads hd) by leaching during housing and storage or superficial runoff during grazing and application, in kg N
NT_{GAS}^{MIN} = Total gaseous losses of organic N from chemical fertilizers (sum over all crops cp and crop areas ha) as NH_3, NO_x or N_2O, in kg N
$NT_{GAS}^{GRAZ+MAN+AP}$ = Total gaseous losses of N manure (sum over all animal species sp and heads hd) as NH_3, NO_x or N_2O, in kg N
$NT_{LEA}^{GRAZ+AP}$ = Total losses of organic N (sum over all animal species sp and heads hd) by leaching below soil, in kg N
NT_{LEA} = N leaching below soils, in kg N
EPR = share of N exported as products in the total N input to the agricultural production;
$LF_{LEA+RUN}^{N2O}$ = Share of N from leaching and runoff, lost as N_2O
$LF_{RUN,S,BAS}^{MAN}$ = Share of N manure lost by leaching and runoff during housing and storage in manure management system s without Nitrate directive measures
$LF_{RUN,S,ND}^{MAN}$ = Share of N manure lost by leaching and runoff during housing and storage in manure management system s with Nitrate directive measures
P_{ND}= National penetration rate for Nitrate directive measures
LF_{RUN}= Share of N deposited on fields or pastures lost by surface runoff

LF_{LEA}= Share of N deposited on fields or pastures lost by leaching below soils

EF_{GRAZ}^{NH3} = Emission factor for NH_3 during grazing, kg N per head

EF_{GRAZ}^{NOx} = Emission factor for NO_x during grazing, kg N per head

EF_{GRAZ}^{N2O} = Emission factor for N_2O during grazing, kg N_2O per head

EF_{MAN}^{NH3} = Emission factor for NH_3 during housing and storage, kg N per head

EF_{MAN}^{NOx} = Emission factor for NO_x during housing and storage, kg N per head

EF_{HOUS}^{N2O} = Emission factor for N_2O during housing, kg N per head

EF_{STOR}^{N2} = Emission factor for N_2 during storage, kg N per head

EF_{AP}^{NH3} = Emission factor for NH_3 during application, kg N per head

EF_{AP}^{NOx} = Emission factor for NO_x during application, kg N per head

EF_{AP}^{N2O} = Emission factor for N_2O during application, kg N_2O per head

EF_{MIN}^{NH3} = Emission factor for NH_3 during application of chemical fertilizers on managed soils, kg N per ha

EF_{MIN}^{NOx} = Emission factor for NO_x during application of chemical fertilizers on managed soils, kg N per ha

EF_{MIN}^{N2O} = Emission factor for N_2O during application of chemical fertilizers on managed soils, kg N_2O per ha

$EF(1)_{LEA+RUN}^{N2O}$ = Emission factor for indirect N_2O-emissions from leaching and runoff, kg N_2O per ha

$EF(2)_{LEA+RUN}^{N2O}$ = Emission factor for indirect N_2O-emissions from leaching and runoff, kg N_2O per head

The loss factor for superficial runoff (LF_{RUN}), which is used for the calculation of surface runoff from grazing animals, manure application upon managed soils and application of mineral fertilizers (see corresponding section under Animal feed production), is differentiated by NUTS2 regions and ranges from 14.67% in Severoiztochen (Bulgaria) to 0.17% in Oevre Norrland (Sweden). For the background of the factors see Velthof et al. (2009). The complete list for all NUTS2 regions is presented in Table A1 in the annex to this chapter. The loss factor for leaching during housing and storage ($LF_{RUN,S}^{MAN}$) depends on the management system *s* (Liquid/Solid) and the national penetration rate of the nitrate directive (P_{ND}). Without the implementation of the nitrate directive measures a general loss factor of 7.18% for solid systems is assumed. For liquid systems CAPRI uses a loss factor of 2% for Belgium, Denmark, Germany, France, Ireland, Netherlands, Sweden, Finland, United Kingdom and Luxemburg, and 5% for all other countries. Where, in contrast, the nitrate directive measures are already implemented, a general loss factor of 3.23% for solid systems and zero losses for liquid systems are applied (see alsoVelthof et al., 2005). For those animal categories, for which solid and liquid systems are not differentiated (poultry, sheep and goats), the values of solid systems are in use. The penetration rates of nitrate directive measures are supposed to be 90% for Denmark, Ireland, Netherlands, Germany, Austria, Belgium, United Kingdom and Finland, 70% for Luxembourg, Italy, France, Sweden, Lithuania and Slovenia, 60% for Spain and Portugal, 50% for Slovakia, Hungary, Czech Republic, Estonia and Cyprus, and 30% for Poland, Bulgaria, Romania, Greece, Latvia and Malta. In the current version of CAPRI the calculation of losses for leaching during housing and storage is confined to nitrate vulnerable zones. Therefore, the loss

factors are multiplied with the regional shares of nitrate vulnerable zones (*NVZ*) (see Velthof et al., 2007).

As mentioned above, the nitrogen supposed to be leached into the groundwater (NT_{LEA}) is derived by applying the loss factor for leaching below soils (LF_{LEA}) to the total N surplus of the agricultural system. LF_{LEA} is specific to regions, ad can be found in Table A1 in the annex to this chapter for all regions. The N-surplus is calculated by summing up all N-imports to the agricultural system and subtracting all N-exports via products, gaseous losses or losses from superficial runoff and leaching during manure management. The remaining part of the surplus (which is not leached) is assumed to volatilize as N_2 (denitrification).

In order to get estimates for the N_2O-emissions from leaching and runoff, NT_{LEA} is first added to NT_{RUN}^{MIN} and $NT_{RUN}^{GRAZ+MAN+AP}$, and then the loss factor $LF_{LEA+RUN}^{N2O}$ is applied. $LF_{LEA+RUN}^{N2O}$ is assumed to be 0.75% in correspondence to the emission factor EF_5, recommended by the IPCC guidelines (see IPCC, 2006: Vol.4, Tab.11.3). Leaching emissions from housing and storage are allocated to animal activities ($EF(2)_{LEA+RUN}^{N2O}$), all other leaching emissions are allocated to crops ($EF(1)_{LEA+RUN}^{N2O}$).

4.2.8. Emissions of N_2O and CO_2 from the cultivation of organic soils

Organic matter stored in organic soils decompose when the conditions change from anaerobic to aerobic ones, which is usually the case when organic soils are drained for agricultural use, and as a consequence carbon and nitrogen are released. Even if in absolute terms the share of arable land or grassland on organic soils is small in most regions and countries, due to the high yearly emissions of CO_2 and N_2O on those soils it cannot be left out. The calculation follows strictly the IPCC 2006 guidelines, applying the following loss factors for kg N and kg C per ha:

Table 4.16: Loss factors for C and N emissions on cultivated organic soils (in kg C or N per ha)

Climate Zone	***N***	***C***	
	Grassland/Cropland	***Grassland***	***Cropland***
Boreal/Cool Temperate	8	250	5000
Warm Temperate	8	2500	10000
Tropical	16	5000	20000

Source: IPCC Guidelines 2006 (Volume 4 Ch11 Tab 11.1, Ch5 Tab 5.6, Ch6 Tab 6.3)

The shares of organic soils are differentiated by grassland S_{HIS}^{GRAS} and cropland S_{HIS}^{CROP}. For EU regions (NUTS2) they are derived from the Agricultural Land Use maps for the year 2000 (see Leip et al., 2008), while for non-European country groups the numbers have been provided by Carre et al. (2009). The shares can be found in the annex (see tables A14 and A15). The information on climate zones S_{CLIM}^{X} is from Carre et.al. (2009, see also 4.3.2.2). For EU regions we assigned each NUTS2 region to one of the three climate zones in order to simplify the calculation.

Emissions per hectare are calculated in the following way:

$$(\text{OS}\,1)\quad EF_{HIS}^{CO2,X} = S_{HIS}^{X} * \sum_{CLIM} LF_{HIS}^{C,X,CLIM} * S_{CLIM}^{X} * \frac{44}{12}$$

$$(\text{OS}\,2)\quad EF_{HIS}^{N2O,X} = S_{HIS}^{X} * \sum_{CLIM} LF_{HIS}^{N,X,CLIM} * S_{CLIM}^{X} * \frac{44}{28}$$

X	Land use category (Grassland/Cropland)
$CLIM$	Climate zone (Boreal/Cold Temperate/Warm Temperate/Tropical)
$EF_{HIS}^{CO2,X}$	CO_2 emissions from the cultivation of organic soils for land use category X in kg CO_2 per ha
$EF_{HIS}^{N2O,X}$	N_2O emissions from the cultivation of organic soils for land use category X in kg N_2O per ha
S_{HIS}^{X}	Share of organic soils for land use category X
$LF_{HIS}^{C,X,CLIM}$	Loss factor for carbon on cultivated histosols for land use category X and climate zone CLIM in kg C/ ha
$LF_{HIS}^{N,X,CLIM}$	Loss factor for N on cultivated histosols for land use category X and climate zone CLIM in kg N/ ha
S_{CLIM}^{X}	Share of climate zone CLIM for land use category X

The transformation to product related emissions is carried out by the yield of the respective product, as described in section 4.4. For non-EU countries we used the average values for crop areas and yields of 10 years (1999-2008), provided by FAO (http://faostat.fao.org; accession date: 23/03/2010).

4.3. Indirect emissions of inputs from other sectors for the life cycle assessment

The main difference between ‘activity’-based calculations, as used in the National Inventories, and ‘LCA’-based calculations is the fact that the former considers only emissions directly created by the agricultural activity, while the latter considers also emissions generated during the production of inputs required to perform those activities. For example, in the sector agriculture, emissions from mineral fertilizer application are estimated, but emissions caused in the production process of these fertilizers are not, or they are rather estimated in the energy and industry sectors (see Table 4.1). The inputs that must be considered are chemical substances such as mineral fertilizer and plant protection components, energy as electricity or fuel, and land. Some of these emission sources are calculated on an ‘activity’-basis as well and need to be transformed to a product-basis at a later stage in the calculations (see sections 4.3.1 and 4.4), others are directly calculated in CAPRI on a product-basis (see section 4.3.2).

4.3.1. Activity-based emissions considered in other sectors of the IPCC guidelines

The following emissions related to inputs produced outside the agricultural sector are calculated on the basis of agricultural activities (hectares or heads). 1) Emissions from the manufacturing of mineral fertilizers, 2) direct and indirect CO_2 emissions from energy use, and 3) emissions and removals for CO_2 in grasslands and croplands, being characterised by different carbon sequestration rates. Their calculation method is described in the following sections.

4.3.1.1 Emissions from Manufacturing of mineral fertilizers

Mineral fertilizers do not only contribute to GHG emissions when applied to fields or pastures, but also during the production process. Emissions occur in form of CO_2 and N_2O. CAPRI uses a simplistic approach with a unique factor for each nutrient (N, P_2O_5, K_2O), except for N which is differentiated by N from urea and N from other nitrogen fertilizers, and for each of the two greenhouse gases The factors include both emissions from N-losses and energy usage in the production process. The calculation corresponds to the following formulas:

$$(FP\ 1)\quad EF_{PRD}^{x} = \sum_{k}\left(N_k * LF_k^x * FS_k\right) + P_{MIN} * LF_P^x + K_{MIN} * LF_K^x$$

N_k = N in chemical fertilizers applied to pastures and crops for fertilizer type k (urea/others), kg per ha

P_{MIN} = P_2O_5 in chemical fertilizers applied to pastures and crops, kg per ha

K_{MIN} = K_2O in chemical fertilizers applied to pastures and crops, kg per ha

FS_K = fraction of applied fertilizer type k (urea/others) in total chemical fertilizer applied

x = N_2O, CO_2

LF_N^x = x-factors during Production of N-fertilizers, kg x per kg N

LF_P^x = x- factors during Production of P_2O_5-fertilizers, kg x per kg N

LF_K^x = x- factors during Production of K_2O -fertilizers, kg x per kg N

EF_{PRD}^x = Emission factor for x-Losses during Production of fertilizers, kg x per ha

The applied N_2O- and CO_2-factors (*LF*) are presented in Table 4.17.

Table 4.17: LF for the N_2O- and CO_2-emissions during the production of mineral fertilizers, in kg gas per ton of nutrient (N, P2O5, K2O)

	CO_2	N_2O
N_{Urea}	4018.9	0.0
N_{Others}	2438.4	9.0
P_2O_5	972.7	4.3
K_2O	140	0.6

Source: Wood,S., Cowie, A. (2004)

4.3.1.2 Energy-related emissions of CO_2 (or CO_{2-eq})

Emissions from On-farm energy use

This section is devoted to the use of energy on the farm-level, which is above all the direct use of fuels and electricity, but also the indirect energy consumption via the construction of buildings or machineries. On-farm energy use has been implemented in CAPRI in form of a sub-module. Since the energy-module is quite comprehensive and uses a large number of input parameters, its presentation will be kept short and be confined to the basic principles. A more thorough description can be found in Kempen and Kraenzlein (2008) and Kraenzlein (2008).

The energy module uses a life-cycle approach and considers direct energy usage in form of fuels and electricity and indirect energy usage from the production of mineral fertilizers, pesticides, buildings and machinery. The results of the energy-module are differentiated by production activities, as it was the case in the previous sections. The greenhouse gas emissions are calculated as $CO_{2\text{-}eq}$, a differentiation by GHG-types, therefore, is not possible.

The methodology for the calculation of energy use is presented in the following sub-sections:

Emissions from direct energy use in form of diesel fuel

The calculation of diesel fuel use is based on the KTBL model (KTBL, 2004), taking into account soil quality (light/medium/heavy), work-process steps (soil preparation/seed and seedbed preparation/fertilizer application/plant protection/harvesting/transport), and plot size (1/2/5/10/20/40/80 ha) on a regional basis. For grassland diesel fuel use is calculated as a function of regional grass yield, cutting behaviour and pasture share. The resulting amount of diesel fuel is then multiplied with the factor 3.08 kg CO_2–equivalent per litre.

Emissions from direct electricity and heating gas energy usage

Electricity is used in many steps of agricultural production. CAPRI calculates emissions from animal production, feedstuff production, greenhouses, irrigation and grain drying. Heating gas usage is considered for animal production, feedstuff production and greenhouses. Electricity usage in animal production is based on coefficients from Boxberger et al. (1997). It takes account of herd size, building type, manure management system (manure storage/daily spread) and space requirement per animal unit. Moreover, for some specific processes (e.g. milk cooling) yield-based or feed-specific parameters are applied. Heating gas requirements are calculated in a similar way but need not account for manure management systems. The preparation of feedstuffs (e.g. drying) is differentiated by feed components (cereals/oilseeds/energy-rich and protein-rich feeds) and the moisture content. Data sources are Bockisch (2000), Sauer (1992), Moerschner (2000) and Keiser (1999). Greenhouses require energy heating and lightening, and are divided in heated and non-heated ones. Energy need from irrigation is based on a method presented in Nemecek et al. (2003) and considers standardized irrigation systems (mobile/fixed), water sources (surface water/reservoir water) and the water quantity. Finally, electricity usage for grain drying is derived by a formula described in Nemecek et al. (2003). In order to get estimates for GHG-emissions the energy usage is multiplied by a factor of 0.54 kg $CO_{2\text{-}eq}$uicalent per kWh for electricity, and 2.46 kg $CO_{2\text{-}eq}$uicalent per Nm^3 for heating gas.

Emissions from indirect energy usage by machinery and buildings

Energy is not only used directly during the agricultural production process but also indirectly by the production of inputs. The most important long-term inputs are machinery and buildings. Data on machinery stocks come from different sources (see Kraenzlein, 2008) and are allocated to activities by the KTBL-approach (see KTBL, 2004). For tractors, as an example, the energy use is a function of machinery stock, engine power class (<40/40-60/61-100/>100 kW), average service life, hours of machinery use, machinery weight, all specific for different plot sizes and soil qualities. For a more detailed description see Kraenzlein (2008). Energy-use assessment of buildings follows the methodology described in Lalive d'Epinay (2000). It differentiates operations and building

materials. In order to guarantee comparability, buildings were categorized according to a standardized approach based on SALCA061 (2006). In general, energy usage is derived from three components, construction energy, disposal energy use and maintenance energy use, all in numbers per m^3. In case of buildings in animal production, for example, those values are calculated for each manure management system (manure storage/daily spread), and then the sum of those components is divided by an average service life, depending on the building type (northern/central/southern European type). In a second step those standardized yearly values are allocated to the different activities by the average space requirement per head, depending on regional herd size, building type and manure management system.

Emissions from Pesticide usage

Energy consumption for Pesticide usage is a rather small part of total plant production energy usage, and an even smaller share is devoted to the production of feedstuffs. In CAPRI it is estimated on the basis of pesticide costs. Those cost terms are based on FADN and EUROSTAT data. In order to achieve a distribution of substances and energy values per substance, data from the FAO statistics (FAO, 2005) are combined with coefficients from SALCAo61 (2006). Finally, CAPRI derives GHG-emissions wit the following coefficients: 7.07 kg CO_2 per kg herbicide, 10.99 kg CO_2 per kg insecticide and 4.31 kg CO_2 per kg fungicide (herbicides, insecticides and fungicides as active substances).

Emissions from Manufacturing of mineral fertilizers

For the methodology and coefficients see section 2.1.2.8.

4.3.1.3 Emissions and removals from Carbon Sequestration of Grassland and Cropland

In addition to the emission sources considered, we have to include permanent carbon sequestration of grasslands in the analysis, in order to get a complete picture of GHG impacts of the livestock sector. This is particularly important in order to prevent biased results in favor of crop feed based systems, due to a higher feed digestibility. Some authors (Soussana et al, 2007, Soussana et al, 2009) claim that in contrast to the carbon equilibrium concept applied by IPCC, grassland is likely to permanently sequester carbon in soils. This would improve the emission balance of grassland based feed systems compared to crop based ones, since sequestration does not occur on croplands. Unfortunately, neither a standardized methodology proposed by the IPCC, nor another generally agreed methodology exists. CAPRI does not have a consistent carbon cycle model implemented, and, therefore, has to rely on numbers reported by the literature. In view of the shortage of data available and the lack of a consensual methodology we apply a simple methodology on the basis of three factors, applying the simplifying assumption that the natural vegetation on cropland and managed permanent grassland would be natural grassland:

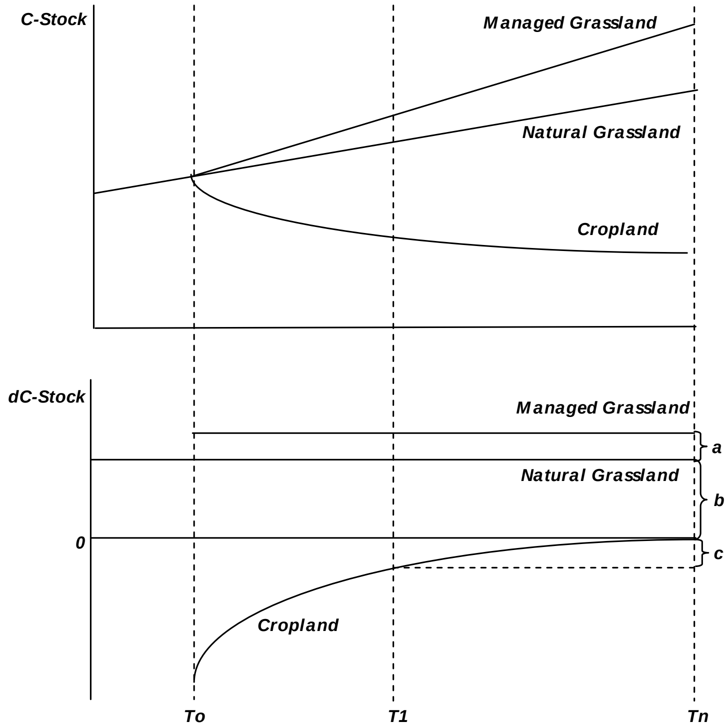
1) A factor EF_{crop} giving the annual carbon sequestration in natural grassland, which is foregone if this land is used for agriculture. This factor is used as additional CO_2 emissions for agricultural land except for cultivations of grass or legumes on arable land

2) A factor giving the actual carbon sequestration in managed permanent grassland. The actual net annual carbon sink of permanent grassland EF_{grass} is calculated as the difference

between the actual carbon sequestration under the managed land used and the carbon sequestration this land would have as natural grassland.

3) A factor EF_{ofar} for agricultural land cultivated with grass or legumes, calculated in the same way as EF_{grass}

For the illustration of the methodological concept see the following graph. The upper part of the graph shows the development of the total carbon stock over time, the lower part the marginal yearly changes. Suppose the initial land use is natural grassland with an assumed permanent C sequestration rate, and at time t_0 there is a change in land use to managed grassland or cropland. In case of managed grassland the permanent rate of C sequestration would jump to a higher value but remain a constant. There is no saturation point and the line in the upper part of the graph becomes simply steeper. This additional carbon removal compared to the natural grassland situation is credited to 'managed grassland'. In contrast, the change to cropland would trigger a non linear decrease of the carbon stock, equivalent to a decreasing marginal carbon loss curve. At the moment t_n this is supposed to stop, the carbon stock is in a new equilibrium. In GGELS the credited removal for managed grassland EF_{grass} or EF_{ofar} corresponds to the segment *a*, and the foregone removal debited to cropland EF_{crop} corresponds to segment *b* in the lower part of the graph. In contrast, the segment *c* is already covered in the section on land use change. What we apply at this point, therefore, is a kind of opportunity cost approach, asking for the net carbon storage effect of using the parcel of land for livestock production compared to leaving it unmanaged. We are aware that the assumption of natural grassland does not correspond to the real natural land cover in many regions. However, first data on natural vegetation were not available at the spatial detail required and secondly we preferred to use consistent values within one methodological framework, and unfortunately equivalent numbers to the ones used for grassland were not available for permanent forest sequestration.



In the following, the calculation of EF_{crop}, EF_{ofar} and EF_{grass} is described, based on the most recent literature for European countries that has been provided by Soussana et. al (2007) and Soussana et.al. (2009), analyzing standardized flux measurements on nine European grassland sites in the frame of the GREENGRASS project. The sites are supposed to represent various European climatic conditions and grassland types, but of course cannot cover the large variety of grassland types in Europe. Four sites are characterized by extensive permanent grasslands only grazed and not cut, three by intensively managed permanent grasslands used both for grazing and cutting, and two recently sown grass-clover swards which are cut only. However, the observed net carbon storage (NCS) differs considerably among these sites and representative numbers for all European grasslands are not easy to be derived.

If we consider natural grasslands as the natural vegetation of European agricultural areas we can assign lost carbon sequestration of natural grasslands as emissions to cropland areas. However, since croplands are generally not established in high altitudes and since we can only account for carbon sequestered by grasslands without any application of mineral or organic fertilizers, only one of the above sites can be regarded as appropriate for the estimation of forgone carbon sequestration on cropland: The Hungarian site Bugac, with an elevation of 140 m, a mean annual rainfall of 500 mm, a mean annual temperature of 10.5 degrees Celsius and managed by extensive grazing without any application of mineral fertilizers. The NCS for Bugac is calculated in the following way in Soussana (2009), considering that there is no extra manure application and no harvested material:

$$(\text{CS}1) \quad NCS = NEE - F_{CH4} + F_{manure} - F_{harvest} - F_{animalproducts} - F_{leach}$$

$$Bugac: \quad 57 = 69 - 1 + 0 - 0 - 1 - 10$$

NEE is the net ecosystem exchange (in contrast to the usual definition we assign sequestration to positive values here), FCH_4 the methane emissions, F_{manure} the manure applied, $F_{harvest}$ and $F_{animalproducts}$ the export of carbon by harvested material and animal products, and F_{leach} is the carbon lost by leaching. However, we cannot take the NCS as it is, but have to remove the effects of management, in case of a site only used for grazing being more or less equivalent with the methane emissions from enteric fermentation and the export in form of animal products. Therefore, we get a coarse estimation of 59 g C per m^2 for natural grasslands. Similarly we can calculate the potential carbon sequestration of natural grassland for all grasslands, now using in addition the values of the French site Laqueuille, with an altitude of 1040 m, mean annual rainfall of 1313 mm, and a mean annual temperature of 8 degrees Celsius. With an *NEE* of 70 g C per m^2 and year and an assumed leaching of 10 g C m^{-2} yr^{-1}, the resulting NCS for natural grassland (60 g C m^{-2} yr^{-1}) is almost the same as in Bugac. So, we get an overall estimate for potential carbon sequestration on natural grasslands of 59-60 g C per m^2 and year.

In a first step we can account this value as emissions of arable land and grassland, because it has been transformed from natural to agriculturally utilized area. In a second step, for grasslands, we have to account for the actually sequestered carbon. Now we can include the results of all nine sites, because the effects of the applied management have to be considered. For simplicity, we have used the average actual NCS values reported in Soussana (2009) for the management types, “only grazing” (NCS=129), “grazing and cutting” (NCS=50), “only cutting” (NCS=71), resulting in an average NCS of 83 g C m^{-2} yr^{-1}. The positive contribution which can be assigned to grassland management, and, therefore, to livestock production is the difference between the potential carbon sequestration of natural grasslands and the actual carbon sequestration of managed grasslands. Similarly, we can use the NCS of “only cutting” for the factor used for arable land cultivated with grass and legumes mixtures. We can summarize the calculation in the following formulas:

$$(\text{CS }2)\quad EF_{crop} = \left(NEE^{BG} - F_{leach}\right) * \frac{44}{12} = \left(69 - 10\right) * \frac{44}{12} = 216$$

$$(\text{CS }3)\quad EF_{gras} = \left(\frac{NEE^{BG} + NEE^{LAe}}{2} - F_{leach} - \frac{NCS_G + NCS_{G+C} + NCS_C}{3}\right) * \frac{44}{12} =$$

$$\left(\frac{69+70}{2} - 10 - \frac{129+50+71}{3}\right) * \frac{44}{12} = -87$$

$$(\text{CS }4)\quad EF_{ofar} = \left(\frac{NEE^{BG} + NEE^{LAe}}{2} - F_{leach} - NCS_C\right) * \frac{44}{12} = \left(\frac{69+70}{2} - 10 - 71\right) * \frac{44}{12} = -42$$

EF_{crop}: Emission factor for lost carbon sequestration for cropland (not grass and legumes) in g CO_2 m^{-2} yr^{-1}

EF_{ofar}: Emission factor for lost carbon sequestration for cropland cultivated with grass and legumes in g CO_2 m^{-2} yr^{-1}

EF_{gras}: Emission factor for lost carbon sequestration for managed permanent grasslands in g CO_2 m^{-2} yr^{-1}

NEE^{BG}: Net ecosystem exchange in the site Bugac in g C m^{-2} yr^{-1}

NEE^{LAe}: Net ecosystem exchange in the site Laqueuille (extensively managed) in g C m^{-2} yr^{-1}

NCS_G: Net carbon storage for extensively managed permanent grasslands in g C m^{-2} yr^{-1}

NCS_{G+C}: Net carbon storage for grazed and cutted permanent grasslands in g C m^{-2} yr^{-1}

NCS_C: Net carbon storage for grasslands only cutted in g C m^{-2} yr^{-1}

F_{leach}: Carbon lost by leaching in g CO_2 m^{-2} yr^{-1}

As a result we get a net contribution to greenhouse gas emissions of arable land not cultivated with grass and legume mixtures of 2.16 tons CO_2 per hectare and year, while for grasslands and arable land with grass/legumes mixtures we get a net reduction of greenhouse gas emissions of 0.87 tons/0.42 tons CO_2 per hectare and year. These factors are applied to cropland and grassland areas for all regions in order to account for carbon sequestration effects.

4.3.2. Emissions directly calculated on product level

Emissions from feed transport and emissions caused by land use change are not related to certain agricultural 'activities' such as the cultivation of a hectare of land, but to the products. For land use change, this is the case as it is not possible nor useful to distinguish, for example, the cultivation of soybean on former agricultural land or on land converted from savanna or forest. Instead, the overall land use change caused by the cultivation of soybean in this example, is assigned to the total harvest of soybean, avoiding thus also the necessity to distinguish between direct and indirect land use change.

The quantification of these two emission sources is presented in the following sections.

4.3.2.1 Emissions from feed transport

Emissions are not only produced during the production process of feeds but also during the transportation from the location of production to the location of usage. This has to be considered in an LCA. Even if the per kg emissions of transport are small in relation to the production related emissions the high feed intake during the life of animals compared to the relatively small output of animal products makes it a not negligible number, especially in case of intensive production systems. However, due to the minor contribution to overall emissions a relatively simple approach has been chosen in CAPRI, rather in order to get an idea of the dimension than to claim an exact estimation. We divide five types of transport systems: Overseas shipping, barges, lorries of 32 tons and 16 tons transport capacity, and railways. 1000 ton-kilometres are supposed to produce 10.57 kg CO_{2-eq} in case of overseas shipping, 45.83 kg in case of a barge, 37.48 kg for railway systems, and 166.43/370.40 kg for lorries with 32/16 tons capacity. The numbers are taken from Kraenzlein (2008). The distribution of transport modes was derived from European Commission (2009) for EU member states MS (S_{TM}^{MS}) and the EU-average (S_{TM}^{EU27}), and from UNECE (2007) for other regions (S_{TM}^{ROW}). The distance matrix between the CAPRI regions was roughly estimated by diverse distance calculation tools provided via internet, like Google Maps. As reference point a centrally located city of a respective country or region was selected. Emissions for EU internal transport is then calculated based on the average distances for the domestic transport of the exporting ($\mathrm{d}_{\mathrm{RE}}^{\mathrm{ME}}$) and the importing country ($\mathrm{d}_{\mathrm{MI}}^{\mathrm{RI}}$) and the distance from the centre of the exporting to the centre of the importing country (d_{ME}^{MI}). Similarly, distances of imports from Non-EU countries are composed of the average domestic transport distances of the importing ($\mathrm{d}_{\mathrm{MI}}^{\mathrm{RI}}$) and the exporting country or

country block (d_{RE}^{ROW}), the distance from the Non-EU country or country block to the EU border (d_{ROW}^{EU}), and the transit distance inside the EU from the EU-border to the centre of the EU country ($d_{SEA}^{MI}, d_{LAND}^{MI}$), depending on whether arriving overseas or overland. The way from the export country border to the EU border is considered only for overseas transport, because overland transport is assumed to occur only in case of exporting country blocks with an EU-border. Finally, for all tradable feed products a minimum retail distance of 50 km is assumed (d^{RET}), served by small lorries with a below 16 tons transport capacity.

$$(FT\ 1)\quad EF_{TRA}^{RI} = \sum_{ME} imp_{ME}^{RI} * \left(d_{ME}^{MI} * \sum_{TM} EF_{TM} * S_{TM}^{EU27} + d_{MI}^{RI} * \sum_{TM} EF_{TM} * S_{TM}^{MI} + d_{RE}^{ME} * \sum_{TM} EF_{TM} * S_{TM}^{ME} \right)$$

$$+ \sum_{ROW} imp_{ROW}^{RI} * \begin{pmatrix} d_{RE}^{ROW} * \sum_{TM} EF_{TM} * S_{TM}^{ROW} + d_{MI}^{RI} * \sum_{TM} EF_{TM} * S_{TM}^{MI} + d_{ROW}^{EU} * EF_{SEA} * S_{SEA}^{INT} + \\ d_{SEA}^{MI} * S_{SEA}^{INT} * \sum_{TM} EF_{TM} * S_{TM}^{EU27} + d_{LAND}^{MI} * S_{LAND}^{INT} * \sum_{TM} EF_{TM} * S_{TM}^{EU27} \end{pmatrix}$$

$$+ d^{RET} * EF_{L16}$$

RE = exporting region
RI = importing region
ME = EU member state exporting
MI = EU member state importing (member state of region RI)
ROW = Exporting Non-EU country or country block
EU = EU border
EF_{TM} = Emission factor of transport mean TM (L16=Lorry with 16 t capacity), kg $CO_{2\text{-eq}}$ per 1000 ton km
imp_{C}^{RI} = Share of a specific feed product in EU-region R which is imported from country (–block) C (ME/ROW) (including imports from other regions of the country)
d_{A}^{B} = Distance from country/region A to country/region B, in 1000 km
d_{SEA}^{MI} = Distance from closest EU main harbour to country MI, in 1000 km
d_{LAND}^{MI} = Distance from EU border to country MI on land way, in 1000 km
d^{RET} = Distance for retail transport, in 1000 km (assumption: 50 km);
S_{TM}^{EU27} = Share of transport means TM in EU-27 (on average)
S_{TM}^{C} = Share of transport mean TM in country (-block) C
S_{MOD}^{INT} = Share of transport category MOD (Sea or land) for transport from Non-EU country border to EU-border
EF_{TRA}^{RI} = Emission factor of Feed transport, in kg $CO_{2\text{-eq}}$ per ton of a specific feed crop

4.3.2.2 Emissions from Land-use-change

In order to complete the life cycle analysis from the point of view of greenhouse gas emissions another emission category has to be considered, which could be neglected if we would look only at

emissions directly created inside Europe. However, since our objective is to account also for indirect effects of European food production, emissions from land use change (LUC) cannot be spared out, even if the assessment is subject to many uncertainties due to a lack of data. Since the study focus is the livestock production in the European Union we only consider LUC emissions of the feed production, but not the emissions assigned to imported animal products. Especially soybeans from South American countries are supposed to contribute considerably to the transformation of savannas and tropical forests to croplands (see Nepstad et. al., 2006; Vera-Diaz et. al., 2008; McAlpine et. al., 2009; Garnett, 2009; Dros, 2004).

However, one of the difficulties is to decide which share of deforested area should be assigned to crop production in general, or to specific crops. One option would be to derive transition probabilities from the comparison of land use maps based on satellite pictures for different years. This has been done for specific regions in past studies (see Fearnside 1995; Jasinski et. al., 2005; Cardille and Foley, 2003;, Baldi and Paruelo, 2008; Morton, et. al., 2006). On global level there are only a few databases available for more then one year (i.e. the MODIS database), and it turned out that the categorization error is substantially larger then the land use change (see Fritz et. al., 2009). Therefore, currently no reasonable land use change estimates can be expected from this kind of analysis.

Another source would be official statistics on land use change, provided by national or international organizations. However, first of all they usually do not provide information on the type of transformation but only on the change of total numbers for various land use categories. From those data one can derive information on the size of the deforested area but not on which share of this area was transformed to cropland, grassland etc. Moreover, while for tropical forests data availability is reasonable, for other land use categories, above all savannas, only little information is provided. Finally, national data sources are of very different quality and often not comparable. The only international time series on land use is provided by the FAO but does not give information on savannas, which is supposed to be the land use category most affected by expansion of feed crops (see Dros, 2004). Moreover, it is not consistent with the FAO data source of agricultural land use.

Even if time series of satellite based land use maps or land use transition probabilities were available in a reasonable quality, however, or the time series of land use statistics were complete, it would not be easy to assign land use changes to certain drivers like wood, soybean or beef production. For example, the fact that we observe a change of forest to grassland in the Amazon region does not necessarily mean that grazing is the driver of this change. It has been pointed out, that the driver is likely to be soybean production in more favored regions, where grassland is transformed to cropland, while the grazing activities are moved to less valuable soils on former forests (see Nepstad, D.C et. al (2006).

In view of those uncertainties, the lack of data and the limited scope of the current study, a simplified approach was chosen in order to provide an idea of the dimension of the expansion of cropland provoked by European livestock production. Based on time series of the FAO crop statistics (http://faostat.fao.org; accession date: 23/03/2010), 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. Finally, the area assigned to a certain crop *c* was divided by the total production of the

crop in the region P_c over the same time period, in order to derive the area of cropland expansion per kg of the crop product LUA_c (see also tables A9a and A9b in the annex).

$$(LUC\,1) \quad sh_c = \frac{ai_c}{\sum_C ai_C}$$

$$(LUC\,2) \quad LUA_c = \frac{sh_c * AI}{P_c}$$

sh_c = Share of crop c in total expansion of agricultural area

ai_c = Expansion of the area for crop c (crops with area reduction not considered), in ha

LUA_c = Expansion of cropland assigned to crop c, in ha per kg

AI = Total Expansion of cropland, in ha

P_c = Total production of crop c, in kg

The transition probabilities from other land uses to cropland p_{LU} are not available and attempts to derive reasonable numbers from satellite data were not successful for reasons explained above. Therefore, three scenarios are defined which should span the space of possible outcomes. In Scenario I all additional cropland is assumed to come from grassland and savannas, Scenario II applies a more likely mix of transition probabilities, and Scenario III can be considered as a maximum emission scenario. The transition probabilities (p_{LU}) for the scenarios II and III are presented in Table 4.18.

Table 4.18: Probabilities p_{LU} for new cropland coming from the following land use categories (in Percent)

Scenario	Country	Grassland	Shrubland	Forests less than 30% canopy cover	Forests above 30% canopy cover
II	Europe (EU and Non-EU), USA, Canada, Russia and former Soviet countries, Japan, Australia and New Zealand	100	0	0	0
	India, China, Mexico, Morocco, Turkey, other Non-European Mediterranean countries	50	50	0	0
	Argentina, Chile, Uruguay, Paraguay, Bolivia, Least developed countries (incl. ACP)	50	40	10	0
	Brazil, Venezuela, Rest of South America, all other countries	50	20	20	10
III	Europe (EU and Non-EU), USA	100	0	0	0
	Canada	0	0	50	50
	Russia and former Soviet countries, Japan, Mexico, Venezuela, Brazil, Chile, Paraguay, Bolivia, Rest of South America, India, Turkey, Least developed countries (incl. ACP)	0	0	0	100
	Australia and New Zealand, Argentina, all other countries	25	25	0	50
	China	40	10		50
	Uruguay	50	25	0	25
	Morocco, other Non-European Mediterranean countries	50	50	0	0

The calculation of the emissions per ha of land use change follow the IPCC guidelines (IPCC, 2006) applying a Tier 1 approach. The following emissions are estimated: 1) Carbon dioxide emissions from the change of biomass carbon stocks (above and below ground) and carbon stocks

in dead organic matter ($EF_{BIO+LIT}^{CO2}$), 2) Carbon dioxide emissions from the change of soil carbon stocks in mineral soils (EF_{SOI}^{CO2}), 3) Methane and N_2O emissions from biomass burning (EF_{BUR}^{CH4}, EF_{BUR}^{N2O}). The following sections provide a detailed description of the applied calculation methods. Once the emissions per hectare of land transformed to cropland are available the total emissions of land use change per kg of feed product ($LUCF_{GAS,CAT}^{c}$), in the following called LUC-Factor, is calculated according to:

$$(\text{LUC } 3) \quad LUCF_{GAS,CAT}^{c} = LUA_c * EF_{CAT}^{GAS}$$

LUA_c = Expansion of cropland assigned to crop c, in ha per kg

EF_{CAT}^{GAS} = Emission factor for GAS (CO_2, CH_4, N_2O) and CAT (BIO+LIT, SOI, BUR), in kg GAS per ha

$LUCF_{GAS,CAT}^{c}$ = Emission factor (LUC-Factor) per kg of feed product c for GAS (CO_2, CH_4, N_2O) and CAT (BIO+LIT, SOI, BUR), in kg GAS per kg

It has to be emphasized that the question of shared assignments is not really addressed with this methodology. Therefore, if e.g. a forest area was cleared for wood and then as a consequence is used as cropland our methodology would assign 100% of the LUC-emissions to cropland and nothing to wood. Similarly, neither land use transition after deforestation (the likely clearing of more than one ha for one ha of land permanently used for agriculture) nor double cropping (more than one crop per year on the same peace of land, which is not documented in the official statistics) is considered. In contrast, the problem of indirect land use change to some degree is evaded by the selected approach, compared to methodologies based on land use changes observed via satellite systems.

Carbon dioxide emissions from the carbon stock change in above and below ground biomass and dead organic matter

Biomass contains a significant carbon stock in both above-ground and below-ground parts. Similarly, a non negligible amount of carbon is stored in dead organic matter like dead wood and litter. If the vegetation is removed this carbon stock gets released to the atmosphere, while the new vegetation will bind carbon again. In case the removed vegetation is replaced by the same kind of vegetation, the removal will not have a significant effect on GHG emissions, because the carbon released to the atmosphere will be absorbed again by the new vegetation. However, different land uses have different carbon stocks, and, therefore, a change of land use can either lead to a net release or a net absorption of carbon, depending on whether the carbon stock of the removed or the new vegetation is larger. Those net emissions are calculated in this section. In the IPCC guidelines the standard Tier 1 calculation approach, which will be applied here, can be found in the Sections 2.3.1-2.3.2, Chapter 2, Volume 4.

Apart from the land use, the carbon stock of above and below ground biomass is supposed to depend on the climate zone and the geographical region. The carbon stock factors $C_{LU,CZ}^{BIO}$ are taken from Carre. al. (2009) and are based on IPCC default factors. A summary is given in Table 4.19:

Table 4.19: Biomass (above and below ground) Carbon Stock factors C^{BIO} by climate zone, geographical region and land use in tons of carbon per ha (Carre et al., 2009)

	Region	Climate Zone								
		Boreal	Cool Temperate Dry	Cool Temperate Wet	Warm Temperate Dry	Warm Temperate Wet	Tropical Dry	Tropical Moist	Tropical Wet	Tropical Mountain
Grassland	All	4.3	3.3	6.8	3.1	6.8	4.4	8.1	8.1	8.1
Shrubland	Europe	7.4	7.4	7.4	37	7.4	n.a.	n.a.	n.a.	n.a.
	Asia continent	7.4	7.4	7.4	37	7.4	39	39	39	39
	Asia islands, Australia etc.	n.a.	7.4	7.4	43	7.4	46	46	46	46
	Africa	n.a.	7.4	7.4	43	7.4	46	46	46	46
	America	7.4	7.4	7.4	50	7.4	53	53	53	53
Forest less than 30% canopy cover	Europe	12	14	14	16	14	n.a.	n.a.	n.a.	n.a.
	Asia continent	12	14	n.a.	16	n.a.	16	21	36	21
	Asia islands, Australia etc.	n.a.	14	43	20	43	19	34	45	34
	Africa	n.a.	n.a.	n.a.	17	n.a.	14	30	40	30
	North America	12	16	79	26	79	25	26	39	26
	South America	12	16	21	26	21	25	26	39	26
Forest above30% canopy cover	Europe	53	87	84	82	84	n.a.	n.a.	n.a.	n.a.
	Asia continent	53	87	n.a.	82	n.a.	83	110	185	110
	Asia islands, Australia etc.	n.a.	87	227	100	227	101	174	230	174
	Africa	n.a.	n.a.	n.a.	88	n.a.	77	156	204	156
	North America	53	93	406	130	406	131	133	198	133
	South America	53	93	120	130	120	131	133	198	133

Similarly, the carbon stock factors for dead organic matter $C_{LU,CZ}^{LIT}$ depend on the climate zone and the land use, but only relevant for forest. The following factors are applied, based on the IPCC default factors (IPCC (2006), Vol.4. Ch. 2, Table 2.2) for litter (values for dead wood are not available).

Table 4.20: Carbon Stock factors for dead organic matter (only litter) C^{LIT} by climate zone and land use in tons of carbon per ha (IPCC, 2006)

	Climate Zone								
	Boreal	Cool Temperate Dry	Cool Temperate Wet	Warm Temperate Dry	Warm Temperate Wet	Tropical Dry	Tropical Moist	Tropical Wet	Tropical Mountain
Forest less than 30% canopy cover	5.6	5.6	4.2	4.8	3.6	0.4	0.4	0.4	0.4
Forest above 30% canopy cover	28	28	21	24	18	2.1	2.1	2.1	2.1

The data on land use are based on three sets of land cover data: 1) The Global Land Cover 2000 product (GLC2000) vs1.1 (http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php), 2) The

GlobCover project (http://ional.esrin.esa.int/index.asp), and 3) The M3 land cover data from McGill University (Ramankutty et. al., 2008). The data set on a 5 minutes pixel level was provided by the administrative arrangement No.: TREN/D1/464-2009-SI2.539303 (see Carre et. al., 2009). For the calculation of land use change emissions six land use classes were used: Cropland, Grassland, Shrubland, Forest with less than 30% canopy cover, Forest above 30% canopy cover, and Other Land Uses. For each Pixel the distribution of land use classes is known from the above land cover map, complemented by the assignment of each Pixel to one of nine climatic zones (Boreal, Cool Temperate Dry, Cool Temperate Wet, Warm Temperate Dry, Warm Temperate Wet, Tropical Dry, Tropical Moist, Tropical Wet, Tropical Mountain Climate). The exact methodology for the assignment to Climate zones and land use classes is described in Carre et.al. (2009). Information on climate and land use on pixel level is then aggregated to the level of those countries and country blocks, which are used in the CAPRI model.

Based on the IPCC guidelines (IPCC (2006), Vol.4. Ch. 2-6), country specific emissions per hectare of area transformed to cropland are calculated in the following way, assuming a zero carbon stock for cropland due to the fact that the biomass is created and removed each year:

$$(LUC\ 4) \quad EF_{LU,CZ}^{CO2} = \sum_{LU,CZ} p_{LU} * C_{LU,CZ}^{BIO+LIT} * sh_{CZ}^{LU} * \frac{44}{12}$$

P_{LU} = Probability that new cropland is coming from land use LU in the respective country or country block

$C_{LU,CZ}^{BIO+LIT}$ = Carbon stock of above and below ground biomass and dead organic matter (litter) of land use LU in climate zone CZ in the respective country or country block, in kg C per ha

sh_{CZ}^{LU} = Share of climate zone CZ in area of land use LU in the respective country or country block;

$EF_{BIO+LIT}^{CO2}$ = CO_2-Emission factor from above and below ground biomass and dead organic matter (litter) in the respective country or country block per ha of area transformed to cropland, in kg CO_2 per ha

The transition probabilities p_{LU} correspond to the respective scenario, the carbon stock factors *C* to the values presented in Table 4.19 and Table 4.20 and the shares of climate zones according to land uses sh_{CZ}^{LU} are derived from the land cover maps and climate zones on pixel level, as described above. 44/12 transforms carbon to CO_2. The resulting LUC-Factors on country level are presented in the annex. The following table shows the weighted values used for imported products from EU and non-EU countries.

Table 4.21: Weighted LUC-Factors for above and below ground biomass and dead organic matter for imported products from EU and non-EU countries in kg CO_2 per kg product

	EU countries			Non-EU countries		
	Scenario I	Scenario II	Scenario III	Scenario I	Scenario II	Scenario III
Soft Wheat	0.007	0.007	0.007	0.070	0.154	1.219
Barley	0.000	0.000	0.000	0.100	0.104	1.488
Maize	0.003	0.003	0.003	0.129	0.511	2.619
Oats	0.007	0.007	0.007	0.034	0.046	0.746
Rye	0.002	0.002	0.002	0.005	0.005	0.005
Other Cereals	0.001	0.001	0.001	0.224	1.072	5.208
Pulses	0.000	0.000	0.000	0.097	0.171	2.752
Rape Seed	0.031	0.031	0.031	0.823	0.903	12.457
Soybeans	0.010	0.010	0.010	0.371	1.684	7.912
Sunflower Seed	0.008	0.008	0.008	0.198	0.209	2.951
Cassava	0.000	0.000	0.000	0.013	0.059	0.347
Rape Oil	0.009	0.009	0.009	0.558	0.567	8.289
Rape Cake	0.047	0.047	0.047	0.953	1.122	14.727
Sunflower Oil	0.000	0.000	0.000	0.076	0.091	1.160
Sunflower Cake	0.004	0.004	0.004	0.222	0.300	3.431
Soybean Oil	0.047	0.047	0.047	0.063	0.257	1.271
Soybean Cake	0.111	0.111	0.111	0.390	1.977	8.669

Carbon dioxide emissions from the soil carbon stock change

Soils contain a considerable amount of carbon, usually in inorganic or organic form. Generally organic and mineral soils are differentiated. According to the land use, the land management and the input of organic material soil carbon increases or decreases over time. Cropland generally is considered as a form of land use which tends to reduce soil carbon even if there are big differences according to the way the soil is managed. In contrast, other forms of land uses like forests or grassland are supposed to have a more favourable effect on soil carbon. A change from forest or grassland to cropland, therefore, is likely to prompt a release of carbon to the atmosphere. This release shall be estimated in this section by a Tier 1 approach following the IPCC guidelines (IPCC, 2006, Vol.4. Ch. 2.3.3). Since inorganic carbon is supposed to be less sensitive to land use and management than organic carbon we focus on the latter. Moreover, since the transformation of organic soils is supposed to release large amounts of carbon to the atmosphere, but there is no information available on the area of organic soils affected by land transformation, we confine our analysis to mineral soils. Finally, it has to be emphasized that information on land management and input of organic material is not available. Therefore, in general default values have been used which need not represent the actual situation of the countries.

The default soil carbon values on pixel level, based on the IPCC default values (IPCC (2006), Vol.4, Ch. 2., Tab. 2.3) presented in Table 4.22, have been provided by the administrative arrangement No.: TREN/D1/464-2009-SI2.539303 (see Carre et al., 2009). The soil parameters applied are taken from the Harmonized World Soil Database (HWSD) from IIASA and FAO. For

the exact translation of the World Reference Base (WRB) soil types to IPCC classes see Carré et al. (2009). The soil carbon values on pixel level were aggregated to countries, climate zones and land use, using the information described in the preceding section.

Table 4.22: Default Soil Organic Carbon Stocks under native vegetation for Mineral Soils ($SOC_{LU,CZ}$) in C tons per ha in 0-30 cm depth

Climate region	HAC soils	LAC soils	Sandy soils	Spodic soils	Volcanic soils
Boreal	68	n.a.	10	117	146
Cold Temperate Dry	50	33	34	n.a.	87
Cold Temperate Wet	95	85	71	115	87
Warm Temperate Dry	38	24	19	n.a.	88
Warm Temperate Wet	88	63	34	n.a.	88
Tropical Dry	38	35	31	n.a.	86
Tropical Moist	65	47	39	n.a.	86
Tropical Wet	44	60	66	n.a.	86
Tropical Mountain Climate	88	63	34	n.a.	86

HAC soils: Soils with high activity clay; LAC soils: Soils with low activity clay

Source: IPCC Guidelines 2006 (IPCC (2006), Vol.4, Ch. 2., Tab. 2.3)

The calculation of the soil carbon emissions per hectare of area transformed to cropland is carried out according to the following formulas, based on IPCC (2006), Vol.4, Ch.2, Equation 2.25:

$(LUC\,5)$

$$EF_{SOIL}^{CO2} = \sum_{LU,CZ} p_{LU} * SOC_{LU,CZ} * \begin{pmatrix} F_{LU,CZ}^{L} * \sum_{MG} \left(F_{LU,CZ,MG}^{M} * sh_{LU,MG}\right) * \sum_{I} \left(F_{LU,CZ,IN}^{I} * sh_{LU,IN}\right) - \\ F_{c,CZ}^{L} * \sum_{MG} \left(F_{c,CZ,MG}^{M} * sh_{c,MG}\right) * \sum_{I} \left(F_{c,CZ,IN}^{I} * sh_{c,IN}\right) \end{pmatrix} * sh_{CZ}^{LU} * \frac{44}{12}$$

P_{LU} = Probability that new cropland is coming from land use LU in the respective country or country block

$SOC_{LU,CZ}$ = Default Soil Carbon stock of land use LU in climate zone CZ in the respective country or country block, in kg C per ha

$F_{LU,CZ}^{L}$ = Stock change factor for land use systems of climate zone CZ and land use LU (c=cropland) in the respective country or country block

$F_{LU,CZ,MG}^{M}$ = Stock change factor for management regime of climate zone CZ, land use LU (c=cropland) and management system MG in the respective country or country block

$F_{LU,CZ,IN}^{I}$ = Stock change factor for input of organic matter of climate zone CZ, land use LU (c=cropland) and input category IN in the respective country or country block

$sh_{LU,MG}$ = Share of management system MG in land use LU in the respective country or country block;

$sh_{LU,IN}$ = Share of input category IN in land use LU in the respective country or country block;

sh_{CZ}^{LU} = Share of climate zone CZ in area of land use LU in the respective country or country block;

EF_{SOIL}^{CO2} = CO_2-Emission factor from the change of soil carbon in the respective country or country block per ha of area transformed to cropland, in kg CO_2 per ha

F^M, F^L and F^I are stock factors which increase or decrease the default (equilibrium) carbon stock *SOC* according to management systems, land use systems and input of organic matter. The values are taken from IPCC (2006), Vol.4, Ch.5, Tab.5.5 and Ch.6, Tab.6.2. $sh_{LU,MG}$, $sh_{LU,IN}$ are country specific shares of management systems and input categories by land uses. Due to a lack of data on management and input they are based on a few simple regional assumptions guaranteeing that carbon stocks do not deviate strongly from default values. The applied values are presented in Table 4.23-Table 4.27. Table 4.28 shows the LUC-Factors for feed products imported from EU and non-EU countries. The detailed country specific LUC-Factors are available in the annex..

Table 4.23: Stock change factors for land use systems (F^L) according to land use and climate zone

Climate Zone	*Cropland*	*Grassland, Shrubland, Forest*
Boreal	0.69	1
Cold Temperate Dry	0.80	1
Cold Temperate Wet	0.69	1
Warm Temperate Dry	0.80	1
Warm Temperate Wet	0.69	1
Tropical Dry	0.58	1
Tropical Moist	0.48	1
Tropical Wet	0.48	1
Tropical Mountain Climate	0.64	1

Source: IPCC Guidelines 2006 (IPCC (2006), Vol.4, Ch. 5., Tab. 5.5)

Table 4.24: Stock change factors for management systems (F^M) according to land use, management and climate zone

	Cropland			*Grassland*				*Shrubland, Forest*
Climate Zone	*Full Tillage*	*Reduced Tillage*	*No Tillage*	*Non degraded*	*Moderately degraded*	*Severely degraded*	*Improved Grassland*	
Boreal	1	1.08	1.15	1	0.95	0.7	1.14	1
Cold Temperate Dry	1	1.02	1.1	1	0.95	0.7	1.14	1
Cold Temperate Wet	1	1.08	1.15	1	0.95	0.7	1.14	1
Warm Temperate Dry	1	1.02	1.1	1	0.95	0.7	1.14	1
Warm Temperate Wet	1	1.08	1.15	1	0.95	0.7	1.14	1
Tropical Dry	1	1.09	1.17	1	0.97	0.7	1.17	1
Tropical Moist	1	1.15	1.22	1	0.97	0.7	1.17	1
Tropical Wet	1	1.15	1.22	1	0.97	0.7	1.17	1
Tropical Mountain Climate	1	1.09	1.16	1	0.96	0.7	1.16	1

Source: IPCC Guidelines 2006 (IPCC (2006), Vol.4, Ch. 5., Tab. 5.5 and Ch.6., Tab.6.2)

Table 4.25: Stock change factors for input of organic matter (F^I) according to land use, input category and climate zone

	Cropland				*Grassland, Shrubland, Forest*
Climate Zone	***Low input***	***Medium Input***	***High input without manure***	***High input with manure***	
Boreal	0.92	1	1.11	1.44	1
Cold Temperate Dry	0.95	1	1.04	1.37	1
Cold Temperate Wet	0.92	1	1.11	1.44	1
Warm Temperate Dry	0.95	1	1.04	1.37	1
Warm Temperate Wet	0.92	1	1.11	1.44	1
Tropical Dry	0.95	1	1.04	1.37	1
Tropical Moist	0.02	1	1.11	1.44	1
Tropical Wet	0.92	1	1.11	1.44	1
Tropical Mountain Climate	0.94	1	1.08	1.41	1

Source: IPCC Guidelines 2006 (IPCC (2006), Vol.4, Ch. 5., Tab. 5.5 and Ch.6., Tab.6.2)

Table 4.26: Shares of management systems ($sh_{LU,MG}$) according to land use, management and country group

	Cropland			*Grassland*			
	Full Tillage	***Reduced Tillage***	***No Tillage***	***Non degraded***	***Moderately degraded***	***Severely degraded***	***Improved Grassland***
Europe (EU and Non-EU), Russia and former Soviet countries, Japan	100	0	0	50	0	0	50
Latin and South America, USA, Canada, Australia, New Zealand	0	0	100	100	0	0	0
China, India, Morocco, Turkey, other Non-European Mediterranean countries, other countries	100	0	0	100	0	0	0
Least developed countries (incl. ACP)	50	0	50	100	0	0	0

Table 4.27: Shares of input categories ($sh_{LU,IN}$) according to land use, input category and country group

	Cropland			
	Low input	***Medium Input***	***High input without manure***	***High input with manure***
Europe (EU and Non-EU), Russia and former Soviet countries, China, India, Japan, Morocco, Turkey, other Non-European Mediterranean countries, other countries	0	100	0	0
Latin and South America, USA, Canada, Australia, New Zealand	100	0	0	0
Least developed countries (incl. ACP)	50	50	0	0

Table 4.28: Weighted LUC-Factors for soil carbon for imported products from EU and non-EU countries in kg CO_2 per kg product

	EU countries			Non-EU countries		
	Scenario I	Scenario II	Scenario III	Scenario I	Scenario II	Scenario III
Soft Wheat	0.035	0.035	0.035	0.306	0.303	0.391
Barley	0.001	0.001	0.001	0.517	0.517	0.683
Maize	0.013	0.013	0.013	0.440	0.428	0.521
Oats	0.036	0.036	0.036	0.101	0.100	0.117
Rye	0.011	0.011	0.011	0.027	0.027	0.027
Other Cereals	0.005	0.005	0.005	0.648	0.622	0.757
Pulses	0.000	0.000	0.000	0.305	0.310	0.543
Rape Seed	0.153	0.153	0.153	4.186	4.184	5.544
Soybeans	0.055	0.055	0.055	1.099	1.041	1.207
Sunflower Seed	0.032	0.032	0.032	1.018	1.019	1.344
Cassava	0.000	0.000	0.000	0.038	0.041	0.052
Rape Oil	0.047	0.047	0.047	2.870	2.871	3.799
Rape Cake	0.247	0.247	0.247	4.772	4.773	6.351
Sunflower Oil	0.002	0.002	0.002	0.386	0.385	0.504
Sunflower Cake	0.017	0.017	0.017	1.099	1.095	1.433
Soybean Oil	0.257	0.257	0.257	0.214	0.211	0.261
Soybean Cake	0.606	0.606	0.606	1.098	1.063	1.276

Methane and N_2O emissions from biomass burning

The conversion of forest, shrubland or grassland to cropland is sometimes carried out by burning of the biomass. The carbon dioxide emissions released have been covered in the section of carbon stock changes in biomass and dead organic matter, because the applied method doesn't differentiate whether the biomass is removed by fire, decay or it is used for construction or furniture and released to the atmosphere at a later stage. However, due to incomplete combustion, the burning of the biomass does not only release carbon dioxide to the atmosphere but also other greenhouse gases, like methane or N_2O. Since those gas emissions, in contrast to carbon dioxide, do only occur in case of fires it is necessary to know which share of the biomass is burned.

Our calculation follows a Tier 1 approach of the IPCC guidelines (IPCC (2006), Vol.4, Ch.2) and due to a lack of data uses generally default values. The general formula is:

$$(LUC\ 6)\quad EF_{BUR}^{GAS} = \sum_{LU,CZ} sh_{LU}^{BUR} * p_{LU} * FUEL_{LU,CZ} * CF_{LU,CZ} * EF_{LU,CZ}^{GAS} * sh_{CZ}^{LU}$$

sh_{LU}^{BUR} = Share of the cleared area in land use LU which is burned in the respective country or country block

P_{LU} = Probability that new cropland is coming from land use LU in the respective country or country block

$FUEL_{LU,CZ}$ = Dead organic matter and live biomass by land use LU and climate zone CZ, in tonnes of dry matter per ha

$CF_{LU,CZ}$ = Combustion factor by land use LU and climate zone CZ, in tonnes of dry matter per ha

$EF_{LU,CZ}^{GAS}$ = Emission factors from Burning for GAS (CH_4, N_2O) by land use LU and climate zone CZ, in kg gas per kg dry matter burnt

sh_{CZ}^{LU} = Share of climate zone CZ in area of land use LU in the respective country or country block;

EF_{BUR}^{GAS} = Emission factors from Burning for GAS (CH_4, N_2O) in the respective country or country block per ha of area transformed to cropland, in kg gas per ha

For the share of area burnt sh_{LU}^{BUR} a value of 50% is assumed for forest and shrubland, and a value of 35% for grassland converted to cropland. This corresponds to the default values recommended by the IPCC guidelines (see IPCC (2006), Vol.4, Ch.5, pp.5.29). Similarly, the values for dead organic matter and live biomass values (*$FUEL_{LU,CZ}$*), indicating the amount of fuel that can be burnt, the applied combustion factors (*$CF_{LU,CZ}$*), which measure the proportion of the fuel that is actually combusted and varies with the size and composition of the fuel, the moisture content and the type of fire, and the default emission factors $EF_{LU,CZ}^{CH4}$ and $EF_{LU,CZ}^{N2O}$ are taken from IPCC (2006), Vol.4, Ch.2, Tab. 2.4-2.6. The applied values are presented in the Table 4.29-Table 4.31. In case of biomass the values for the land use category "Forest less than 30% canopy cover" are generally 20% of the default values for the respective forest category. Table 4.32 and Table 4.33 show the weighted LUC-Factors for feed products imported from other EU or non-EU countries. The detailed values on country level can be found in the annex.

Table 4.29: Dead organic matter and live biomass (FUEL) by land use and climate zone in tons dry matter per ha

Climate Zone	*Grassland*	*Shrubland*	*Forest above 30% canopy cover*	*Forest less than 30% canopy cover*
Boreal	4.1	14.3	41.0	8.2
Cold Temperate Dry	4.1	14.3	50.4	10.8
Cold Temperate Wet	4.1	14.3	50.4	10.8
Warm Temperate Dry	5.2	14.3	50.4	10.8
Warm Temperate Wet	4.1	14.3	50.4	10.8
Tropical Dry	5.2	14.3	83.9	16.8
Tropical Moist	5.2	14.3	160.4	32.0
Tropical Wet	5.2	14.3	160.4	32.0
Tropical Mountain Climate	5.2	14.3	160.4	32.0

Source: IPCC Guidelines 2006 (IPCC (2006), Vol.4, Ch. 2., Tab. 2.4)

Table 4.30: Combustion factor values (CF) by land use and climate zone

Climate Zone	*Grassland*	*Shrubland*	*Forest above 30% canopy cover*	*Forest less than 30% canopy cover*
Boreal	0.92	0.72	0.34	0.34
Cold Temperate Dry	0.92	0.72	0.45	0.45
Cold Temperate Wet	0.92	0.72	0.45	0.45
Warm Temperate Dry	0.92	0.72	0.45	0.45
Warm Temperate Wet	0.92	0.72	0.45	0.45
Tropical Dry	0.92	0.72	0.36	0.55
Tropical Moist	0.92	0.72	0.36	0.55
Tropical Wet	0.92	0.72	0.36	0.55
Tropical Mountain Climate	0.92	0.72	0.36	0.55

Source: IPCC Guidelines 2006 (IPCC (2006), Vol.4, Ch. 2., Tab. 2.6)

Table 4.31: CH_4 and N_2O-Emission factors (EF) by land use and climate zone, in g per kg dry matter

Climate Zone	*Grassland*		*Shrubland*		*Forest above 30% canopy cover*		*Forest less than 30% canopy cover*	
	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O
Boreal	2.3	0.21	2.3	0.21	4.7	0.26	4.7	0.26
Cold Temperate Dry	2.3	0.21	2.3	0.21	4.7	0.26	4.7	0.26
Cold Temperate Wet	2.3	0.21	2.3	0.21	4.7	0.26	4.7	0.26
Warm Temperate Dry	2.3	0.21	2.3	0.21	4.7	0.26	4.7	0.26
Warm Temperate Wet	2.3	0.21	2.3	0.21	4.7	0.26	4.7	0.26
Tropical Dry	2.3	0.21	2.3	0.21	6.8	0.20	6.8	0.20
Tropical Moist	2.3	0.21	2.3	0.21	6.8	0.20	6.8	0.20
Tropical Wet	2.3	0.21	2.3	0.21	6.8	0.20	6.8	0.20
Tropical Mountain Climate	2.3	0.21	2.3	0.21	6.8	0.20	6.8	0.20

Source: IPCC Guidelines 2006 (IPCC (2006), Vol.4, Ch. 2., Tab. 2.5)

Table 4.32: Weighted CH_4 LUC-Factors for biomass burning for imported products from EU and Non-EU countries in g CH_4 per kg product

	EU countries			Non-EU countries		
	Scenario I	Scenario II	Scenario III	Scenario I	Scenario II	Scenario III
Soft Wheat	0.001	0.001	0.001	0.012	0.033	0.265
Barley	0.000	0.000	0.000	0.019	0.019	0.245
Maize	0.001	0.001	0.001	0.022	0.098	0.660
Oats	0.001	0.001	0.001	0.008	0.010	0.107
Rye	0.000	0.000	0.000	0.001	0.001	0.001
Other Cereals	0.000	0.000	0.000	0.032	0.242	1.566
Pulses	0.000	0.000	0.000	0.019	0.028	0.289
Rape Seed	0.005	0.005	0.005	0.155	0.174	2.081
Soybeans	0.001	0.001	0.001	0.052	0.364	2.278
Sunflower Seed	0.002	0.002	0.002	0.038	0.039	0.501
Cassava	0.000	0.000	0.000	0.002	0.010	0.106
Rape Oil	0.001	0.001	0.001	0.106	0.107	1.369
Rape Cake	0.006	0.006	0.006	0.183	0.198	2.347
Sunflower Oil	0.000	0.000	0.000	0.014	0.016	0.202
Sunflower Cake	0.001	0.001	0.001	0.041	0.058	0.625
Soybean Oil	0.006	0.006	0.006	0.012	0.046	0.306
Soybean Cake	0.014	0.014	0.014	0.067	0.376	2.286

Table 4.33: Weighted N_2O LUC-Factors for biomass burning for imported products from EU and Non-EU countries in g N_2O per kg product

	EU countries			Non-EU countries		
	Scenario I	Scenario II	Scenario III	Scenario I	Scenario II	Scenario III
Soft Wheat	0.000	0.000	0.000	0.001	0.002	0.011
Barley	0.000	0.000	0.000	0.002	0.002	0.014
Maize	0.000	0.000	0.000	0.002	0.005	0.022
Oats	0.000	0.000	0.000	0.001	0.001	0.005
Rye	0.000	0.000	0.000	0.000	0.000	0.000
Other Cereals	0.000	0.000	0.000	0.003	0.010	0.046
Pulses	0.000	0.000	0.000	0.002	0.002	0.012
Rape Seed	0.001	0.001	0.001	0.014	0.015	0.112
Soybeans	0.000	0.000	0.000	0.005	0.015	0.068
Sunflower Seed	0.000	0.000	0.000	0.003	0.004	0.027
Cassava	0.000	0.000	0.000	0.000	0.001	0.003
Rape Oil	0.000	0.000	0.000	0.010	0.010	0.075
Rape Cake	0.001	0.001	0.001	0.017	0.018	0.127
Sunflower Oil	0.000	0.000	0.000	0.001	0.001	0.010
Sunflower Cake	0.000	0.000	0.000	0.004	0.004	0.031
Soybean Oil	0.001	0.001	0.001	0.001	0.002	0.011
Soybean Cake	0.001	0.001	0.001	0.006	0.017	0.072

4.4. Life cycle assessment: calculation of product based emissions along the supply chain

The Life cycle approach (LCA) is the attempt not only to consider emissions directly created during the livestock production process but also those emissions created indirectly by the production and delivery of inputs used for livestock production. This requires not only an extension of the sectoral scope, as described in the preceding sections, but also of the regional scope, since inputs imported from non-European countries have to be considered. Moreover, up to now we have calculated emissions partly on the level of agricultural activities, partly on the level of products. Some emissions are only related to crop activities or products and not yet related to animals via the use of feed as an input to animal production. In order to aggregate all those emissions and in order to make them comparable we have to relate them to the same unit, in LCA terminology the functional unit.

This section describes the way how, along the supply chain, emissions from crop activities were assigned to crop products, emissions of crop products were assigned to animal activities via the feed input, and, finally, how all emissions available on the level of animal activities were assigned to animal products. Moreover, it is explained which accounting system was used and how emissions from imported products were integrated in the results.

In the following the functional unit is one kilogram of animal product. The considered products are beef, pork, poultry, meat from sheep and goats, milk from cows, sheep and goats and eggs. As functional unit for meat we use the carcass of the animal, which is between 54% and 60% for (beef, sheep and goats), 78% (pigs) and 80% (poultry) of the live weight. Milk is standardized at a fat content of 4% for cow milk, and 7% for sheep and goat milk, and for eggs we consider the weight of the whole egg including the shell. The considered gases are CH_4, N_2O, N_2, NO_X, NH_3 and CO_2, greenhouse gases generally expressed in terms of the whole gas weight, N_2, NO_X, NH_3 in terms of the N-weight. Emissions of greenhouse gases are reported also as total GHG emissions, in kilogram of $CO_{2\text{-eq}}$ per kilogram of functional unit.

In case of multiple outputs of one production activity, the transformation from activity based emissions (per unit of production activity like hectares or livestock heads) to product based emissions is done in basis of defined allocation keys. This can be done on the basis of the emission creating process (causal allocation) or on the basis of the product output (in either physical terms or economic terms). In general we use the N-content of the products, which, at least for N-related emissions, serves both as an indicator of the emission creation and the product output, protein being the most important nutrient. The only exception for this general principle is methane emissions. For those activities for which the calculation of methane emissions was based on a Tier 2 method, net energy requirements were used for the distribution of emissions instead of the default method. Currently this is only the case for dairy cows and other cattle activities. For manure applied on agricultural land we apply the method of system expansion.

Emission sources listed in Table 4.34 are taken into account and in a first step calculated per unit of animal or crop production activity (see preceding sections).

Table 4.34: Emission categories in the CAPRI LCA

Gas	*Rel. to*	*Source of emission*	*Stage of the process where the emission occurs*	*Regional scope*	*Sign*
CH_4	A	Enteric fermentation	Direct emissions (Housing and Grazing)	regional	+
CH_4 N_2O	A	Manure	Direct emissions (Housing, Storage, Grazing and Application to managed soils)	regional	+
N_2O	C	Mineral fertilizer	Direct emissions from application for the production of feed crops	regional + imports	+
N_2O	C	Mineral fertilizer	Direct emissions from application for the production of feed crops saved due to the application of manure	imports	+
N_2O	C	Mineral fertilizer	Direct emissions from application for the production of non feed crops saved due to the application of manure	regional	-
N_2O CO_2	C	Mineral fertilizer	Emissions from the production of fertilizer for the production of feed crops	regional + imports	+
N_2O CO_2	C	Mineral fertilizer	Emissions from the production of fertilizer saved due to the application of manure in the production of feed crops	imports	+
N_2O CO_2	C	Mineral fertilizer	Emissions from the production of fertilizer saved due to the application of manure in the production of non feed crops	regional	-
N_2O	A	Manure	Indirect emissions following N deposition of volatilized NH_3/NO_X (Housing, Storage, Grazing Application to managed soils)	regional	+
N_2O	C	Mineral fertilizer	Indirect emissions following N deposition of volatilized NH_3/NO_X from mineral fertilizer application for the production of feed crops	regional + imports	+
N_2O	C	Mineral fertilizer	Indirect emissions following N deposition of volatilized NH_3/NO_X from mineral fertilizer application saved due to the application of manure for the production of feed crops	imports	+
N_2O	C	Mineral fertilizer	Indirect emissions following N deposition of volatilized NH_3/NO_X from mineral fertilizer application saved due to the application of manure for the production of non feed crops	regional	-
N_2O	A	Manure	Indirect emissions following from Leaching and Runoff (Housing, Storage, Grazing Application to managed soils)	regional	+
N_2O	C	Mineral fertilizer	Indirect emissions following from Leaching and Runoff from mineral fertilizer application for the production of feed crops	regional + imports	+
N_2O	C	Mineral fertilizer	Indirect emissions following from Leaching and Runoff from mineral fertilizer application saved due to the application of manure for the production of feed crops	imports	+
N_2O	C	Mineral fertilizer	Indirect emissions following from Leaching and Runoff from mineral fertilizer application saved due to the application of manure for the production of non feed crops	regional	-
CO_2	C	Transport	Transport of feed	regional + imports	+
CO_2	C	Processing	Feed processing	regional + imports	+
CO_2	C	Diesel	Emissions from the production of feed	regional + imports	+
CO_2	A+ C	Other fuels	Emissions from the production of feed and livestock production (housing and storage)	Regional + (imports)	+
CO_2	A+ C	Electricity	Emissions from the production of feed and livestock production (housing and storage)	Regional + (imports)	+
CO_2	A+ C	Buildings and machinery	Indirect emissions in the production of buildings and machinery for the production of feed and livestock	Regional + (imports)	+
CO_2	C	Pesticides	Indirect emissions from the production of pesticides for the production of feeds	regional + imports	+

A: Animal production, C: Crop production

Emissions from manure management in housing, storage and application to managed soils will generally be accounted to the livestock sector of the livestock producing region, while emissions from mineral fertilizer production and application and mineral fertilizers that were saved due to the application of manure will be allocated to the respective crops. Other emission sources can be related to animal or crop production or both (see second column of Table 4.34). The fifth column shows whether only regional emissions are considered or also emissions from imported products, while the sixth column sketches whether the position will increase or decrease the emissions allocated to the livestock production. Important to notice is that, in order to be consistent, saved mineral fertilizer emissions due to the application of manure have to be subtracted from the emissions allocated to livestock production, in case of non-feed products produced in the respective region. Those emissions would also have been created without the existence of regional livestock production, and, therefore, have to be assigned to the crops. In contrast, saved mineral fertilizer emissions for the production of imported feeds have to be added, because, according to the accounting system, emissions from manure application are assigned to the livestock activities of the exporting region. This, however, is only justified to the extent that emissions from manure application exceed those which would be created by the alternative use of mineral fertilizers. Therefore, the latter must be assigned to the livestock production of the feed importing region.

In order to allocate the crop related emissions from feed production to animal products we first have to distribute them to animal activities according to their feed consumption. Therefore, we have to calculate emissions for each feed product considering also emissions from imported feeds. If there is only one output for one production activity emissions of crop products are simply the emissions per unit of the crop activity divided by the crop yield. Emissions from imported crops are calculated in the same way for each source country and added according to the import shares of those source countries. However, in order to spread the mistakes in trade statistics over all countries and regions and in order to avoid erratic changes of emissions due to changing import sources we differentiate only imports from non-EU countries and from EU countries. In other words, for each feed product there is only one emission factor for imports from EU countries and one for imports from non-EU countries, which is used for all regions.

In case of multiple outputs, i.e. cereal activities producing also straw, emissions are allocated to the products by the N-contents of the products. Similarly, emissions of secondary feed products, being processed from crop products, are derived from the primary crop product’s emissions weighted by the N-content in the following way:

$$(LCA\ 1) \quad E_s^r = \frac{\left[\sum_p \left(P_p^r * E_p^r * sh_p^{rr}\right) + \sum_p \sum_c \left(P_p^r * E_p^c * sh_p^{rc}\right)\right] * N_s^r}{\sum_p YNS_p^r}$$

p	Primary crop products which enter in the production process of secondary product s
c	Country group (EU and Non_EU)
E_s^r, E_p^r, E_p^c	Emissions per kg of secondary product s (primary product p) in region r (country group c)
P_p^r	Quantity of primary crop product p which enters in the processing of secondary products in region r
sh_p^{rr}	Share of primary crop product p in region r which is produced within the region r

sh_p^{rc}	Share of primary crop product p in region r which is imported from country group c
N_s^r	N-content (kg N per kg) of secondary product s produced in region r
YNS_p^r	Aggregated N-content (kg N of whole regional output) of all secondary products produced by primary crop product p in region r

Emissions of secondary feed products, therefore, are built only on the basis of emissions from the primary products, while emissions of the processing itself are not considered. We have to keep in mind that, in order to avoid double counting, the calculations have to be carried out for each of the above listed emission categories, if related to crop production. So, the outcome of the first step is not an aggregated emission from feed per unit of the feed product, but emissions per unit for each feed product and each crop related emission category. Those emissions are then allocated to animal activities by the feed consumption, (creating numbers for emissions per unit of each animal activity).

In a second step we have to allocate those animal activity based emissions to animal products. It has to be noted, that in contrast to emissions from feed, imported animal products are not considered here, since we are only interested in the emissions of regional animal production. So, the emissions of imported feed enter the calculation, the emissions of imported animal products don't. Again, in case of one product per activity the allocation is quite straightforward, summing up the emissions of the activity and its animal inputs and dividing it by the products output. However, in case of multiple outputs of one production activity, like milk and beef, an allocation key has to be defined. As mentioned above, we have chosen the net energy requirements (for pregnancy, lactation, growth etc.) for methane emissions of dairy cows and other cattle activities, and the N-content of products for all other cases. Net energy requirements are calculated according to the standard method recommended by the IPCC and used for the calculation of methane emissions in CAPRI (see section on emissions from enteric fermentation). In general the processes for raising and fattening young animals will be allocated to the meat output, while the activities of dairy and suckling cows, sheep and goats for milk or laying hens are split up into the raising of young animals during pregnancy (which is allocated to meat) and the respective product (milk and eggs). The logic behind is, that raising and fattening activities both produce meat by growing animals, even if it will be sold on the market at a later stage like in the case of heifers raised to become dairy cows, which will then be slaughtered after having been used as producer of milk and calves for several years. In contrast, i.e. the dairy cow activity doesn't aim at the growth of the cow any more. The main purpose is the production of milk and young calves. So, even if dairy cows are slaughtered and, therefore, deliver meat output, the meat was not created within the dairy cow activity but already before, when the young cow was raised. So, emissions of the dairy cow activity are allocated to the milk output and the production of young calves.

The calculation shall first be demonstrated by the example of sheep and goat milk and meat for emissions related to nitrogen. The average weight of a young lamb entering the fattening process is assumed to be 6 kg and the N-content of a lamb 0.0245 kg N per kg of live weight. In order to allocate the N-content of the live body to lamb meat one has to divide the N-content of lamb by the relation of carcass weight to live weight, which is assumed to be 0.6. Sheep and goat milk, finally, is supposed to contain 0.0053 kg N per kg of milk. The output of the sheep and goat fattening activity is only meat, while the output of the sheep and goat milk activity is meat, milk and lambs.

Therefore, the emissions from the sheep and goat fattening activity will be allocated to sheep and goat meat, while the emissions from the sheep and goat milk activity have to be distributed to milk, meat and lamb output. For an assumed output of 0.9 lambs, 40 kg of milk and 4 kg of meat, and an input of 0.2 lambs per unit of the milk activity (which corresponds to 1 lamb per five heads of milk sheep/goat) the product shares (S_{MEAT}, S_{MILK}, S_{LAMB}) of emissions for the activity will be calculated in the following way (for meat only the substance growth is considered, which is the meat output minus the meat input from lambs coming into the process):

$$(LCA\ 2)\quad S_{MILK} = \frac{40*0.0053}{40*0.0053+0.9*6*0.0245+(4-0.2*6*0.6)*0.0245/0.6} = 0.44$$

$$(LCA\ 3)\quad S_{MEAT} = \frac{(4-0.2*6*0.6)*0.0245/0.6}{40*0.0053+0.9*6*0.0245+(4-0.2*6*0.6)*0.0245/0.6} = 0.28$$

$$(LCA\ 4)\quad S_{LAMB} = \frac{0.9*6*0.0245}{40*0.0053+0.9*6*0.0245+(4-0.2*6*0.6)*0.0245/0.6} = 0.28$$

Emissions per kg of milk and meat are then derived by the subsequent formulas based on activity related emissions:

$$(LCA\ 5)\quad E_{MEAT}^{PR} = \frac{\left(E_{FAT}^{ACT} + E_{MILK}^{ACT} * S_{LAMB} * \frac{I_{FAT}^{LAMB}}{O_{MILK}^{LAMB}}\right) * LEVL_{FAT} + E_{MILK}^{ACT} * \left(S_{MEAT} + S_{LAMB} * \frac{I_{MILK}^{LAMB}}{O_{MILK}^{LAMB}}\right) * LEVL_{MILK}}{Y_{MEAT}}$$

$$(LCA\ 6)\quad E_{MILK}^{PR} = \frac{E_{MILK}^{ACT} * S_{MILK} * LEVL_{MILK}}{Y_{MILK}}$$

E_{MILK}^{PR}	Emissions per kg of milk
E_{MEAT}^{PR}	Emissions per kg of meat
E_{FAT}^{ACT}	Emissions per unit of fattening activity
E_{MILK}^{ACT}	Emissions per unit of milk production activity
I_{FAT}^{LAMB}	Number of lamb input per unit of fattening activity
I_{MILK}^{LAMB}	Number of lamb input per unit of milk activity
O_{MILK}^{LAMB}	Number of lambs produced per unit of milk activity
$LEVL_{FAT}$	Regional level of fattening activity
$LEVL_{MILK}$	Regional level of milk activity
Y_{MEAT}	Regional output of meat
Y_{MILK}	Regional output of milk

The emissions per kg of milk are simply the emissions per unit of milk activity (emissions per head of milk sheep) times the regional level of the activity (number of heads) and the N-share of milk S_{MILK}, divided by the regional milk output Y_{MILK}. In contrast, emissions per kg of meat require a

more complex calculation. On the one hand, meat is produced by the milk and the meat activity, requiring the sum of emissions from both activities divided by the regional meat output Y_{MEAT}. On the other hand, due to the input requirement of young lambs into the fattening activity, emissions from fattening do not only include emissions from the fattening activity E_{FAT}^{ACT} but also a share of the emissions from the milk activity. Therefore, the input of lambs per unit of the fattening activity I_{FAT} (usually one) has to be multiplied by the lamb share of the milk activity emissions S_{LAMB} * E_{MILK}^{ACT} divided by the lamb output per unit of the milk activity O_{MILK} (0.9 in our numeric example above). Emissions for meat coming from the milk activity are calculated in a similar way, including the emissions from the lamb input and the emissions from the growth of sheep in the milk activity.

For the other animal categories the calculation steps are presented in the following formulas and tables, while Table 4.38 gives a short overview of which factors determine the product shares of emissions (S) in case of multiple outputs. The tables of feed inputs for animal products, based on the allocation by the N-content, are available in the annex.

Dairy cows and other cattle

$$(LCA\ 7)\quad S_{MILK}^{DCOW} = \frac{O_{DCOW}^{MILK} * NC_{MILK}}{O_{DCOW}^{MILK} * NC_{MILK} + \left(O_{DCOW}^{CF} + O_{DCOW}^{CM}\right) * W_{CALF} * NC_{CALF}}$$

$$(LCA\ 8)\quad S_{CALF}^{COW} = \frac{\left(O_{COW}^{CF} + O_{COW}^{CM}\right) * W_{CALF} * NC_{CALF}}{O_{COW}^{MILK} * NC_{MILK} + \left(O_{COW}^{CF} + O_{COW}^{CM}\right) * W_{CALF} * NC_{CALF}}$$

$$(LCA\ 9)\quad E_{CF}^{ACT} = \frac{E_{DCOW}^{ACT} * LEVL_{DCOW} * \frac{S_{CALF}^{DCOW} * O_{DCOW}^{CF}}{O_{DCOW}^{CF} + O_{DCOW}^{CM}} + E_{SCOW}^{ACT} * LEVL_{SCOW} * \frac{S_{CALF}^{SCOW} * O_{SCOW}^{CF}}{O_{SCOW}^{CF} + O_{SCOW}^{CM}}}{Y_{CF}}$$

$$(LCA\ 10)\quad E_{CM}^{ACT} = \frac{E_{DCOW}^{ACT} * LEVL_{DCOW} * \frac{S_{CALF}^{DCOW} * O_{DCOW}^{CM}}{O_{DCOW}^{CF} + O_{DCOW}^{CM}} + E_{SCOW}^{ACT} * LEVL_{SCOW} * \frac{S_{CALF}^{SCOW} * O_{SCOW}^{CM}}{O_{SCOW}^{CF} + O_{SCOW}^{CM}}}{Y_{CM}}$$

$$(LCA\ 11)\quad E_{BEEF}^{PR} = \frac{\begin{pmatrix} \left(E_{FAT,CF}^{ACT} + E_{CF}^{ACT}\right) * LEVL_{CF}^{FAT} + \left(E_{FAT,CM}^{ACT} + E_{CM}^{ACT}\right) * LEVL_{CM}^{FAT} \\ + \left(E_{HEIF}^{ACT} + E_{RS,CF}^{ACT} + E_{CF}^{ACT}\right) * LEVL_{HEIF} + \\ \left(E_{BULF}^{ACT} + E_{RS,CM}^{ACT} + E_{CM}^{ACT}\right) * LEVL_{BULF} + \\ \left(E_{HEIR}^{ACT} + E_{RS,CF}^{ACT} + E_{CF}^{ACT}\right) * LEVL_{SCOW} * I_{SCOW}^{CF} + \\ \left(E_{HEIR}^{ACT} + E_{RS,CF}^{ACT} + E_{CF}^{ACT}\right) * LEVL_{DCOW} * I_{DCOW}^{CF} \end{pmatrix}}{Y_{BEEF}}$$

$$(LCA\ 12)\quad E_{MILK}^{PR} = \frac{E_{DCOW}^{ACT} * S_{MILK}^{DCOW} * LEVL_{DCOW}}{Y_{MILK}}$$

E_{BEEF}^{PR}	Emissions per kg of beef
E_{MILK}^{PR}	Emissions per kg of milk
E_{CF}^{ACT}	Emissions of female calf production per cow (mix of dairy cows and suckler cows)
E_{CM}^{ACT}	Emissions of male calf production per cow (mix of dairy cows and suckler cows)
E_{DCOW}^{ACT}	Emissions per unit of dairy cow activity
E_{SCOW}^{ACT}	Emissions per unit of suckler cow activity
$E_{FAT,CF}^{ACT}$	Emissions per unit of female calf fattening activity
$E_{FAT,CM}^{ACT}$	Emissions per unit of male calf fattening activity
$E_{RS,CF}^{ACT}$	Emissions per unit of female calf raising activity

$E_{RS,CM}^{ACT}$	Emissions per unit of male calf raising activity
E_{HEIF}^{ACT}	Emissions per unit of heifers fattening activity
E_{HEIR}^{ACT}	Emissions per unit of heifers raising activity
E_{BULF}^{ACT}	Emissions per unit of bull fattening activity
S_{CALF}^{COW}	Share of cow (COW: DCOW or SCOW) emissions allocated to production of calves
S_{MILK}^{DCOW}	Share of dairy cow emissions allocated to production milk
O_{DCOW}^{CF}	Number of female calves produced per unit of dairy cow activity
O_{DCOW}^{CM}	Number of male calves produced per unit of dairy cow activity
O_{DCOW}^{MILK}	Milk output per unit of dairy cow activity
O_{SCOW}^{CF}	Number of female calves produced per unit of suckler cow activity
O_{SCOW}^{CM}	Number of male calves produced per unit of suckler cow activity
$LEVL_{DCOW}$	Regional level of dairy cow activity
$LEVL_{SCOW}$	Regional level of suckler cow activity
$LEVL_{HEIF}$	Regional level of heifers fattening activity
$LEVL_{BULF}$	Regional level of bull fattening activity
$LEVL_{CF}^{FAT}$	Regional level of female calf fattening activity
$LEVL_{CM}^{FAT}$	Regional level of male calf fattening activity
I_{DCOW}^{CF}	Number of female calf input per unit of dairy cow activity
I_{SCOW}^{CF}	Number of female calf input per unit of suckler cow activity
Y_{BEEF}	Regional output of beef
Y_{MILK}	Regional output of milk
Y_{CF}	Regional output of female calves
Y_{CM}	Regional output of male calves
NC_{MILK}	N content (kg N per kg) per kg of milk
NC_{CALF}	N content (kg N per kg) per kg of calf output
W_{CALF}	Average live weight of calf output

Table 4.35: Fixed parameter values for the calculation of the N content for Dairy cows and other cattle in CAPRI

Parameter	***Values used in CAPRI***
NC_{MILK}	0.0054
NC_{CALF}	0.030
W_{CALF}	50

Pigs:

$$(LCA\ 13)\quad S_{PORK}=\frac{\left(O_{SOWS}^{PORK}-I_{SOWS}^{PLTS}*W_{PLTS}*CA_{PIGS}\right)*NC_{PIGS}/CA_{PIGS}}{O_{SOWS}^{PLTS}*W_{PIGS}*NC_{PIGS}+\left(O_{SOWS}^{PORK}-I_{SOWS}^{PLTS}*W_{PLTS}*CA_{PIGS}\right)*NC_{PIGS}/CA_{PIGS}}$$

$$(LCA\ 14)\quad S_{PLTS}=\frac{O_{SOWS}^{PLTS}*W_{PIGS}*NC_{PIGS}}{O_{SOWS}^{PLTS}*W_{PIGS}*NC_{PIGS}+\left(O_{SOWS}^{PORK}-I_{SOWS}^{PLTS}*W_{PLTS}*CA_{PIGS}\right)*NC_{PIGS}/CA_{PIGS}}$$

$$(LCA\ 15)\quad E_{PORK}^{PR}=\frac{\left(E_{FAT}^{ACT}+E_{SOWS}^{ACT}*S_{PLTS}*\frac{I_{FAT}^{PLTS}}{O_{SOWS}^{PLTS}}\right)*LEVL_{FAT}+E_{SOWS}^{ACT}*\left(S_{PORK}+S_{PLTS}*\frac{I_{SOWS}^{PLTS}}{O_{SOWS}^{PLTS}}\right)*LEVL_{SOWS}}{Y_{PORK}}$$

E_{PORK}^{PR}	Emissions per kg of pork
E_{FAT}^{ACT}	Emissions per unit of fattening activity
E_{SOWS}^{ACT}	Emissions per unit of piglets production activity
S_{PLTS}	Share of piglet production emissions allocated to production of piglets
S_{PORK}	Share of piglet production emissions allocated to production of pork
I_{FAT}^{PLTS}	Number of piglet input per unit of fattening activity
I_{SOWS}^{PLTS}	Number of piglet input per unit of piglet production activity
O_{SOWS}^{PLTS}	Number of piglets produced per unit of piglet production activity
O_{SOWS}^{PORK}	Pork output per unit of piglet production activity
$LEVL_{FAT}$	Regional level of fattening activity
$LEVL_{SOWS}$	Regional level of piglet production activity
Y_{PORK}	Regional output of pork
W_{PLTS}	Average live weight of piglet output
NC_{PIGS}	N content (kg N per kg) per kg of pig output
CA_{PIGS}	Relation of carcass weight to live weight for pigs

Table 4.36: Fixed parameter values for the calculation of the N content for Pigs in CAPRI

Parameter	***Values used in CAPRI***
NC_{PIGS}	0.0251
CA_{PIGS}	0.78
W_{PLTS}	20

Poultry:

$(LCA\ 16)$

$$S_{EGGS} = \frac{O_{HENS}^{EGGS} * NC_{EGGS}}{O_{HENS}^{EGGS} * NC_{EGGS} + O_{HENS}^{CHI} * W_{CHI} * NC_{POUL} + \left(O_{HENS}^{MEAT} - I_{HENS}^{CHI} * W_{CHI} * CA_{POUL}\right) * NC_{POUL} / CA_{POUL}}$$

$(LCA\ 17)$

$$S_{MEAT} = \frac{\left(O_{HENS}^{MEAT} - I_{HENS}^{CHI} * W_{CHI} * CA_{POUL}\right) * NC_{POUL} / CA_{POUL}}{O_{HENS}^{EGGS} * NC_{EGGS} + O_{HENS}^{CHI} * W_{CHI} * NC_{POUL} + \left(O_{HENS}^{MEAT} - I_{HENS}^{CHI} * W_{CHI} * CA_{POUL}\right) * NC_{POUL} / CA_{POUL}}$$

$(LCA\ 18)$

$$S_{CHI} = \frac{O_{HENS}^{CHI} * W_{CHI} * NC_{POUL}}{O_{HENS}^{EGGS} * NC_{EGGS} + O_{HENS}^{CHI} * W_{CHI} * NC_{POUL} + \left(O_{HENS}^{MEAT} - I_{HENS}^{CHI} * W_{CHI} * CA_{POUL}\right) * NC_{POUL} / CA_{POUL}}$$

$(LCA\ 19)$

$$E_{MEAT}^{PR} = \frac{\left(E_{FAT}^{ACT} + E_{HENS}^{ACT} * S_{CHI} * \frac{I_{FAT}^{CHI}}{O_{HENS}^{CHI}}\right) * LEVL_{FAT} + E_{HENS}^{ACT} * \left(S_{MEAT} + S_{CHI} * \frac{I_{HENS}^{CHI}}{O_{HENS}^{CHI}}\right) * LEVL_{HENS}}{Y_{MEAT}}$$

$(LCA\ 20)$ $$E_{EGGS}^{PR} = \frac{E_{HENS}^{ACT} * S_{EGGS} * LEVL_{HENS}}{Y_{EGGS}}$$

E_{MEAT}^{PR}	Emissions per kg of poultry meat
E_{EGGS}^{PR}	Emissions per egg
E_{FAT}^{ACT}	Emissions per unit of fattening activity
E_{HENS}^{ACT}	Emissions per unit of laying hens activity
S_{CHI}	Share of laying hens production emissions allocated to the production of chicken
S_{MEAT}	Share of laying hens production emissions allocated to production of meat
S_{EGGS}	Share of laying hens production emissions allocated to production of eggs
I_{FAT}^{CHI}	Number of chicken input per unit of fattening activity
I_{HENS}^{CHI}	Number of chicken input per unit of laying hens activity
O_{HENS}^{CHI}	Number of chicken produced per unit of laying hens activity
O_{HENS}^{EGGS}	Number of eggs produced per unit of laying hens activity
O_{HENS}^{MEAT}	Meat output per unit of laying hens activity
$LEVL_{FAT}$	Regional level of fattening activity

$LEVL_{HENS}$	Regional level of laying hens activity
Y_{MEAT}	Regional output of meat
Y_{EGGS}	Regional output of eggs
W_{CHI}	Average live weight of young chicken output
NC_{EGGS}	N content (kg N per kg) per egg
NC_{POUL}	N content (kg N per kg) per kg of poultry
CA_{POUL}	Relation of carcass weight to live weight for poultry

Table 4.37: Fixed parameter values for the calculation of the N content for Poultry in CAPRI

Parameter	***Values used in CAPRI***
NC_{EGGS}	0.019
NC_{POUL}	0.033
CA_{POUL}	0.8
W_{CHI}	NA

Table 4.38: Factors for the distribution of emissions in case of multiple outputs

Product	***Animal activities***	***N-emissions, CO_2-emissions***	***Methane emissions***
Milk	Dairy cows and other cattle	Milk yield, N-content of milk	Energy requirement for lactation
	Sheep and goats	Milk yield, N-content of milk	Milk yield, N-content of milk
Meat	Dairy cows and other cattle	Meat yield, N content of animals and relation of carcass to live weight, output coefficients of young animals	Energy requirement for growth and pregnancy
	Pigs, poultry, sheep and goats	Meat yield, N content of animals and relation of carcass to live weight, input and output coefficients of young animals	Meat yield, N content of animals and relation of carcass to live weight, input and output coefficients of young animals
Eggs	Poultry	Eggs yield, N-content of eggs	Eggs yield, N-content of eggs
Primary crop products (soft wheat, oats, straw etc.)		N content of primary product	N content of primary product
Secondary feed products (rape seed oil, rape seed cake etc.)		N content of secondary products, input and output quantity of primary and secondary products	N content of secondary products, input and output quantity of primary and secondary products

5. COMPARISON OF EU LIVESTOCK GHG EMISSIONS DERIVED BY CAPRI WITH OFFICIAL GHG INVENTORIES

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5.1. Basic input parameters

For the calculation of GHG emissions related to livestock production the livestock numbers are one of the basic input parameters. As one can see in Table 5.1 the differences between CAPRI and inventory data 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.

Another crucial parameter is the assumed nitrogen excretion of livestock presented in Table 5.2. It is the basic input for the calculation of N_2O-emissions from livestock. In CAPRI the excretion is not an exogenous parameter but is calculated as the difference between nitrogen intake and nitrogen retention of animals (see Chapter 4, Eq. GR 1). For cattle and poultry deviations are generally low, while for swine, sheep and goats the differences are larger. In case of swine the usually higher CAPRI values partly compensate the lower livestock numbers shown in Table 5.1.

Only indirectly related to livestock production is the use of mineral fertilizers for the production of crops. Crops are used as feed and, therefore, will enter the livestock emissions in the life cycle assessment. In CAPRI the total amount of nitrogen applied as mineral fertilizers is based on member state data of the European Fertilizer Manufacturer’s Association as published by FAOSTAT and expert questionnaire data from EFMA reporting average mineral fertilizer application rates per crop and Member States (see IFA/IFDC/FAO, 2003). The application to different crop groups can be found in Table 5.3. In contrast, the national inventories do not provide crop specific application rates but only the total amount of mineral fertilizers applied. The comparison to CAPRI numbers shows that there is a good level of correspondence between CAPRI and national inventories for mineral fertilizer application.

Table 5.1: Livestock numbers in 1000 heads (annual average population for 2004)

	Dairy cows		Other Cattle		Swine		Sheep and goats		Poultry[5]	
	1000 heads								Mio heads	
	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]
Belgium[1]	611	555	1852	2333	4990	6283	167	153	26	33
Denmark	579	563	894	1082	7721	13233	103	135	22	17
Germany	4312	4285	7463	8911	20239	25659	2043	2874	142	123
Greece	151	221	437	393	551	942	11718	14391	28	30
Spain	1105	1069	6220	5532	13808	25226	23279	25591	169	158
France	3938	4011	13551	15455	9799	11598	9726	10505	231	266
Ireland	1140	1136	4507	5088	943	1696	4455	6711	15	17
Italy	2034	1838	5546	4466	7566	8972	7744	9084	145	191
Netherlands	1517	1471	1592	2296	6409	11153	1375	1518	74	88
Austria	552	538	1393	1513	2340	3125	317	383	15	13
Portugal	327	336	1112	1073	1382	2314	2515	3824	33	33
Sweden	401	404	970	1225	1218	1818	247	472	14	17
Finland	327	324	571	645	882	912	61	116	11	10
United Kingdom	2109	2131	7016	8467	2865	5160	20407	35972	180	174
Cyprus	26	24	31	32	245	471	482	657	4	3
Czech Republic	415	573	735	855	2172	3127	101	128	32	25
Estonia	112	117	117	133	176	340	32	42	2	2
Hungary	291	309	299	424	2543	4385	1161	1465	46	50
Lithuania	424	434	329	358	442	1073	36	49	7	8
Latvia	170	186	132	185	153	436	33	53	2	4
Malta	6	8	9	12	37	77	8	20	1	1
Poland	2577	2796	2048	2557	8672	16988	311	494	125	130
Slovenia	130	134	288	317	170	534	82	142	6	3
Slovakia	156	232	212	308	651	1149	287	360	13	14
Bulgaria	363	365	351	335	401	982	2564	2367	13	21
Romania	1489	1566	1813	1208	2233	6495	7428	8086	57	87
EU-27	*25264*	*25627*	*59490*	*65203*	*98607*	*154149*	*96681*	*125591*	*1412*	*1521*

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories, 3) “Other cattle” in National Inventories included in “Other animals”, 4) “Other cattle” in National Inventories included in “Dairy cows”, 5) Values in 1.000000 heads

Table 5.2: N output per head in form of manure for 2004: CAPRI-Values compared to the values reported by the member states (National Inventories of 2010 for 2004)

	Dairy cows		Other Cattle		Swine		Sheep and goats		Poultry	
	[kg head^{-1} yr^{-1}]								[kg (1000 head)$^{-1}$ yr^{-1}]	
	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]
Belgium[1]	95	108	47	56	18.4	10.5	5.5	8.4	424	606
Denmark	194	132	62	38	22.8	8.5	8.8	16.9	844	794
Germany	106	130	40	41	18.4	10.2	5.0	7.7	521	744
Greece	97	70	47	50	16.1	16.0	7.9	12.0	522	600
Spain	108	68	51	52	17.5	9.2	6.8	5.8	562	451
France	105	100	53	58	16.6	16.3	7.7	19.2	612	600
Ireland	88	85	48	65	15.2	8.3	5.1	6.2	469	344
Italy	97	116	39	50	20.0	11.6	6.2	16.2	474	538
Netherlands	119	NA	38	NA	15.8	NA	4.8	0.0	494	NA
Austria	90	95	40	47	17.3	12.9	5.2	13.0	486	550
Portugal	121	103	68	49	19.9	9.7	8.4	6.9	635	555
Sweden	180	123	61	41	21.3	9.1	8.2	6.2	732	396
Finland	92	118	30	46	12.3	16.9	4.0	9.7	428	571
United Kingdom	142	112	53	49	17.6	10.0	6.7	5.5	581	672
Cyprus	134	70	43	50	21.5	16.0	9.2	28.1	576	600
Czech Republic	114	100	43	70	19.8	20.0	4.7	20.5	555	600
Estonia	122	90	42	32	18.1	12.8	6.5	16.6	577	600
Hungary	149	109	51	46	26.9	8.2	7.9	19.9	685	600
Lithuania	99	88	39	50	17.5	20.0	6.7	16.0	607	600
Latvia	139	71	57	50	24.4	10.0	10.8	6.0	825	600
Malta	155	NE	51	NE	24.1	NE	8.3	0.0	618	NA
Poland	91	87	36	59	16.6	13.6	6.2	6.8	577	349
Slovenia	85	103	38	42	15.0	11.6	5.0	20.8	426	600
Slovakia	119	100	42	60	18.0	16.2	6.9	16.0	621	741
Bulgaria	116	70	49	50	21.6	20.0	9.5	11.1	683	600
Romania	96	70	39	50	18.8	20.0	7.8	16.7	576	600

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories, 3) “Other cattle” in National Inventories included in “Other animals”, 4) “Other cattle” in National Inventories included in “Dairy cows”,

Table 5.3: Application of chemical nitrogen fertilizers in CAPRI compared to those reported by the member states (National Inventories of 2010 for 2004) in 1000 t of N

	CAPRI								NI[1]
	Cereals	Pulses	Oilseeds	Grassland	Fodder Maize	Other feed cops	Other crops	Total	Total
Belgium	66.7	0.0	2.9	51.1	0.9	2.2	38.2	162.1	163.5
Denmark	129.3	0.1	26.1	12.0	3.1	16.8	15.6	203.0	203.2
Germany	1010.6	3.9	302.8	233.0	75.8	14.3	152.2	1792.5	1827.8
Greece	116.3	0.5	0.3	34.4	0.2	0.4	83.4	235.5	229.5
Spain	408.5	4.6	22.3	251.9	0.7	0.8	342.1	1030.8	1045.1
France	1376.0	34.0	309.0	316.9	55.7	10.2	177.7	2279.4	2108.9
Ireland	37.1	0.1	0.5	200.9	1.3	103.9	9.2	353.0	357.0
Italy	368.3	1.2	8.5	81.8	15.5	0.5	223.4	699.0	765.1
Netherlands	44.9	0.2	0.7	87.3	7.6	15.4	114.3	270.4	289.8
Austria	66.8	0.3	5.2	16.8	0.9	1.2	11.0	102.2	94.5
Portugal	19.7	0.0	0.3	38.1	1.2	0.5	28.8	88.6	118.6
Sweden	89.0	0.2	2.2	11.4	1.0	57.2	10.5	171.4	176.8
Finland	114.9	0.3	8.4	25.3	0.0	1.3	9.9	160.1	152.5
United Kingdom	494.5	0.9	26.9	404.0	6.3	79.6	62.2	1074.4	1109.4
Cyprus	3.9	0.0	0.1	0.0	0.0	1.8	3.1	9.0	7.7
Czech Republic	160.4	0.6	67.4	21.9	25.8	0.5	17.5	294.0	194.8
Estonia	15.2	0.1	3.9	6.3	0.1	1.8	1.3	28.7	24.8
Hungary	253.2	1.8	46.1	10.9	1.2	0.3	24.6	338.3	263.7
Lithuania	64.3	0.6	0.2	30.2	1.7	7.6	12.0	116.6	123.0
Latvia	18.6	0.1	0.0	12.4	0.1	0.0	6.7	37.9	31.7
Malta	0.0	0.0	0.0	0.0	0.0	0.4	0.5	0.9	0.5
Poland	629.3	3.4	84.3	76.5	5.9	16.4	122.7	938.6	805.5
Slovenia	21.0	0.0	0.9	23.0	11.4	0.9	5.5	62.7	27.2
Slovakia	53.0	0.3	16.8	3.9	9.2	1.2	6.5	90.9	71.9
Bulgaria	92.9	0.4	26.5	0.1	1.6	1.1	15.0	137.4	148.5
Romania	168.1	1.1	14.0	0.3	0.3	8.8	43.2	235.8	243.0
EU-27	*5822.3*	*54.7*	*976.3*	*1950.2*	*227.4*	*344.9*	*1537.3*	*10913.1*	*10584.0*

Sources: EEA, 2010, own calculations; 1) NI=National Inventories

5.2. CH_4-emissions from enteric fermentation

Emission factors and total emissions of methane emissions from enteric fermentation are presented in Table 5.4 and Table 5.5. In general the correspondence of inventory data and CAPRI-data is satisfactory. For the EU-27 CAPRI reports emissions of 7.260 Mio tons, which is about 3% above the sum of the values reported by the member states. In some countries (i.e.: Denmark, United Kingdom, Romania and Bulgaria) total emissions show stronger deviations, usually reporting higher values in the CAPRI-system than in the National Inventories. Differences mainly come from the animal categories “dairy cows” and “other cattle”, since other animal categories play a less important role with respect to total emissions from enteric fermentation. In first line differences are due to higher emission factors, in case of Romania also to deviating livestock numbers.

The calculation details for the CAPRI model are provided in Chapter 4 (Section 4.2.1). Therefore, 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.

Table 5.4: Emission factors for methane emissions from enteric fermentation in kg per head and year (annual average population for 2004)

	Dairy cows		Other Cattle		Swine		Sheep and goats		Poultry	
	[kg head^{-1} yr^{-1}]								[kg (1000 head)$^{-1}$ yr^{-1}]	
	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]
Belgium[1]	103	116	46	45	1.5	1.5	8.0	7.5	0	0
Denmark	177	126	58	36	1.5	1.1	8.0	16.9	0	0
Germany	138	112	54	45	1.5	1.0	8.0	7.8	0	0
Greece	140	92	53	56	1.5	1.5	8.0	6.5	0	0
Spain	130	92	45	54	1.5	0.9	8.0	8.2	0	0
France	137	116	55	49	1.5	1.2	8.0	10.1	0	0
Ireland	103	109	50	54	1.5	0.4	8.0	6.0	0	0
Italy	109	111	41	46	1.5	1.5	8.0	7.7	0	0
Netherlands	113	125	38	37	1.5	1.5	8.0	7.4	0	0
Austria	117	113	50	56	1.5	1.5	8.0	7.6	0	19
Portugal	113	113	57	58	1.5	1.4	8.0	9.6	0	0
Sweden	190	129	72	54	1.5	1.5	8.0	8.0	0	0
Finland	123	121	39	0	1.5	1.5	8.0	7.3	0	0
United Kingdom	146	97	57	43	1.5	1.5	8.0	4.8	0	0
Cyprus	139	100	41	58	1.5	1.5	8.0	6.3	0	137
Czech Republic	155	110	58	52	1.5	1.5	8.0	7.7	0	0
Estonia	141	120	51	48	1.5	0.8	8.0	7.8	0	0
Hungary	178	124	64	56	1.5	1.5	8.0	7.8	0	15
Lithuania	121	95	41	44	1.5	1.5	8.0	6.4	0	0
Latvia	156	108	58	52	1.5	1.5	8.0	7.2	0	0
Malta	126	100	45	48	1.5	1.5	8.0	7.1	0	100
Poland	117	93	43	48	1.5	1.5	8.0	7.0	0	0
Slovenia	106	97	51	49	1.5	1.7	8.0	7.5	0	0
Slovakia	162	100	63	53	1.5	1.5	8.0	9.4	0	0
Bulgaria	138	81	51	56	1.5	1.5	8.0	7.1	0	0
Romania	132	92	49	56	1.5	1.0	8.0	5.0	0	0

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories, 3) "Other cattle" in National Inventories included in "Other animals", 4) "Other cattle" in National Inventories included in "Dairy cows"

Table 5.5: Methane emissions from enteric fermentation in 1000 tons for 2004: CAPRI-Values compared to the values reported by the member states (National Inventories of 2010 for 2004)

	Dairy cows		Other Cattle		Swine		Sheep and goats		Poultry		Other animals		***Total emission***	
	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	***Capri***	***NI[2]***
Belgium[1]	62.6	64.4	84.4	104.8	7.5	9.4	1.3	1.1	0.0	NE	0.0	0.9	155.8	180.7
Denmark	102.5	71.1	51.5	38.5	11.6	14.6	0.8	2.3	0.0	NE	0.0	3.7	166.5	130.2
Germany	596.8	481.7	405.5	396.8	30.4	25.1	16.3	22.5	0.0	NO	0.0	13.6	1049.0	939.7
Greece	21.2	20.4	23.3	22.0	0.8	1.4	93.7	93.9	0.0	NE	0.0	1.3	139.1	138.9
Spain	144.2	98.5	277.2	300.5	20.7	23.0	186.2	210.2	0.0	NE	0.0	6.3	628.4	638.4
France	541.4	463.3	746.2	752.5	14.7	13.3	77.8	105.7	0.0	NA	0.0	9.7	1380.1	1344.6
Ireland	117.1	124.2	224.6	273.6	1.4	0.7	35.6	40.3	0.0	NE	0.0	1.4	378.8	440.2
Italy	221.4	204.9	225.2	206.6	11.4	13.5	61.9	69.7	0.0	NA	0.0	21.2	519.9	515.9
Netherlands	171.6	183.5	59.7	85.0	9.6	16.7	11.0	11.3	0.0	NE	0.0	2.3	251.9	298.9
Austria	64.6	60.9	69.6	85.1	3.5	4.7	2.5	2.9	0.0	0.3	0.0	1.9	140.2	155.7
Portugal	36.9	38.0	63.5	62.5	2.1	3.2	20.1	36.8	0.0	NO	0.0	2.6	122.6	143.1
Sweden	76.0	52.1	69.5	66.1	1.8	2.7	2.0	3.8	0.0	NO	0.0	9.9	149.2	134.5
Finland[3]	40.3	39.1	22.1	IE	1.3	1.4	0.5	0.8	0.0	NE	0.0	34.9	64.2	76.2
United Kingdom	307.4	205.8	398.1	366.3	4.3	7.7	163.3	173.2	0.0	NA	0.0	6.2	873.0	759.2
Cyprus[4]	3.6	2.4	1.3	1.9	0.4	0.7	3.9	4.1	0.0	0.4	0.0	0.0	9.1	9.5
Czech Republic	64.3	63.3	42.3	44.5	3.3	4.7	0.8	1.0	0.0	NA	0.0	0.4	110.6	113.8
Estonia	15.8	13.9	5.9	6.4	0.3	0.3	0.3	0.3	0.0	NE	0.0	0.1	22.2	21.1
Hungary	51.8	38.4	19.0	23.8	3.8	6.6	9.3	11.5	0.0	0.8	0.0	1.3	84.0	82.3
Lithuania	51.2	41.3	13.5	15.7	0.7	1.6	0.3	0.3	0.0	NE	0.0	1.1	65.6	60.0
Latvia	26.6	20.1	7.6	9.7	0.2	0.7	0.3	0.4	0.0	NE	0.0	0.3	34.7	31.1
Malta	0.8	0.8	0.4	0.6	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	1.4	1.8
Poland	301.4	261.0	89.0	121.6	13.0	25.5	2.5	3.5	0.0	NO	0.0	5.8	405.8	417.4
Slovenia	13.8	13.1	14.6	15.7	0.3	0.9	0.7	1.1	0.0	NE	0.0	0.3	29.3	31.0
Slovakia	25.3	23.2	13.3	16.4	1.0	1.7	2.3	3.4	0.0	NO	0.0	0.1	41.9	44.8
Bulgaria	50.0	29.6	18.0	18.7	0.6	1.5	20.5	16.8	0.0	NO	0.0	4.2	89.2	70.7
Romania	196.0	144.7	88.9	67.6	3.4	6.5	59.4	40.4	0.0	NE	0.0	17.3	347.7	276.5
EU-27	*3304.4*	*2759.6*	*3034.2*	*3102.8*	*147.9*	*188.2*	*773.4*	*857.4*	*0.0*	*1.6*	*0.0*	*146.7*	*7259.9*	*7056.3*

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories, 3) "Other cattle" in National Inventories included in "Other animals", 4) "Other cattle" in National Inventories included in "Dairy cows"

5.3. CH_4-emissions from manure management

Table 5.6 and Table 5.7 show the methane emission factors and total methane emissions from manure management. According to CAPRI, total emissions for the EU-27 and for the year 2004 account for 1.306 Mio. tons, which is about 46% below the values reported by the member states. Among others, especially the values for swine differ substantially and show a heavy impact on total values. Moreover, the largest part of the total deviation comes from two countries, Spain and France. In Spain the differences come mainly from the different livestock numbers (see Table 5.1). In France they are due to the allocation to the temperate climate zone, which leads to a substantial overestimation of emissions in inventory data.

In general the observed differences between CAPRI and inventory data are higher for emissions from manure management than those from enteric fermentation, which is due to methodological differences and the large number of critical parameters described in Section 4.2.2. Differences are, above all, the use of detailed temperature data in CAPRI compared to a basic grouping into three

climatic zones in inventory reports, based on the IPCC guidelines of 1996 (IPCC, 1997). Furthermore, default values for maximum methane producing capacities (MCFs) have generally been reduced significantly for liquid manure management systems, while they have been increased for solid systems from the IPCC guidelines 1996 to 2006. Since CAPRI uses the newer values while the inventories are based on the 1996 guidelines (IPCC, 1997), results can be expected to differ considerably. For the distribution of manure management systems CAPRI applies the shares of the RAINS database, while inventories are based on national values (see Table 4.6). Finally, in CAPRI the volatile solid excretion (VS) is derived from digestibility and gross energy values (see Chapter 4, WP 7.1, Eq. MM1) being subject to methodological differences explained in Section 5.2.

Table 5.6: Emission factors for methane emissions from manure management in kg per head and year (annual average population for 2004)

	Dairy cows		Other Cattle		Swine		Sheep and goats		Poultry	
	[kg head^{-1} yr^{-1}]								[kg (1000 head)$^{-1}$ yr^{-1}]	
	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]
Belgium[1]	11.3	16.8	2.7	3.0	6.4	9.8	0.19	0.59	13.7	38.5
Denmark	34.2	30.1	4.9	4.1	6.5	2.0	0.19	0.51	21.7	33.3
Germany	31.6	26.6	6.4	5.7	6.4	3.8	0.19	0.22	23.2	29.0
Greece	19.5	19.0	4.7	13.0	9.2	7.0	0.23	0.24	23.6	117.0
Spain	13.7	14.4	1.0	1.2	8.5	9.2	0.23	0.22	21.0	9.9
France	11.0	18.3	2.7	19.9	6.7	20.9	0.19	0.27	22.7	117.8
Ireland	13.8	20.7	3.6	11.1	6.6	12.4	0.19	0.15	22.6	331.1
Italy	16.8	14.5	4.4	7.5	7.3	7.6	0.23	0.21	23.1	79.8
Netherlands	20.4	37.5	4.8	6.6	6.5	4.5	0.19	0.22	7.8	31.5
Austria	12.1	8.6	2.6	4.0	6.4	1.3	0.19	0.18	23.7	74.4
Portugal	13.1	5.2	2.1	1.5	10.2	21.3	0.26	1.46	22.5	18.4
Sweden	28.8	17.0	4.3	5.8	6.5	3.1	0.19	0.19	24.0	78.0
Finland	16.0	13.5	1.9	0.0	6.6	0.0	0.19	0.18	23.1	224.9
United Kingdom	20.4	23.7	2.5	4.2	6.6	7.1	0.19	0.11	20.8	78.0
Cyprus	12.6	42.0	1.7	21.0	6.6	19.0	0.19	0.31	23.3	260.0
Czech Republic	9.2	14.0	3.2	6.0	3.2	3.0	0.19	0.18	23.5	78.0
Estonia	10.2	9.3	3.5	3.4	3.2	3.2	0.19	0.19	24.8	78.0
Hungary	8.0	7.1	1.8	2.0	3.3	10.9	0.19	0.24	23.5	119.5
Lithuania	12.9	13.8	2.4	5.7	3.2	17.3	0.19	0.15	25.7	78.0
Latvia	8.0	6.0	1.7	4.0	3.3	4.0	0.19	0.17	30.0	78.0
Malta	4.8	44.0	0.8	20.0	6.6	10.0	0.19	0.25	24.3	117.0
Poland	9.1	9.3	2.4	5.9	3.2	6.5	0.19	0.15	23.8	78.0
Slovenia	16.5	48.1	5.5	18.5	3.4	14.4	0.19	0.18	21.9	78.0
Slovakia	17.6	4.0	4.6	3.8	3.2	4.0	0.19	0.18	24.6	78.0
Bulgaria	9.8	19.1	2.0	13.0	3.4	7.2	0.19	0.25	26.2	117.0
Romania	8.8	19.0	2.5	13.0	3.3	7.0	0.19	0.16	26.0	18.0

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories, 3) “Other cattle” in National Inventories included in “Other animals”, 4) “Other cattle” in National Inventories included in “Dairy cows”

Table 5.7: Methane emissions from manure management in 1000 tons for 2004: CAPRI-Values compared to the values reported by the member states (National Inventories of 2010 for 2002)

	Dairy cows		Other Cattle		Swine		Sheep and goats		Poultry		Other animals		***Total emission***	
	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	***Capri***	***NI***[2]
Belgium[1]	6.9	9.3	4.9	6.9	31.9	61.7	0.0	0.1	0.4	1.3	0.0	0.2	44.1	79.5
Denmark	19.8	17.0	4.4	4.4	50.5	25.8	0.0	0.1	0.5	0.6	0.0	2.3	75.2	50.1
Germany	136.2	114.1	47.8	50.4	129.0	98.5	0.4	0.6	3.3	3.6	0.0	2.1	316.7	269.3
Greece	3.0	4.2	2.1	5.1	5.0	6.6	2.7	3.5	0.7	3.6	0.0	0.2	13.5	23.1
Spain	15.1	15.4	6.0	6.6	117.7	231.6	5.4	5.7	3.5	1.6	0.0	2.6	147.7	263.4
France	43.2	73.4	36.6	307.4	66.0	242.1	1.9	2.8	5.2	31.3	0.0	0.9	153.0	658.0
Ireland	15.7	23.4	16.1	56.3	6.2	21.1	0.8	1.0	0.3	5.5	0.0	0.1	39.1	107.5
Italy	34.2	26.7	24.5	33.4	55.6	68.1	1.8	1.9	3.3	15.3	0.0	4.7	119.4	150.1
Netherlands	30.9	55.1	7.6	15.0	41.8	50.2	0.3	0.3	0.6	2.8	0.0	0.4	81.1	123.9
Austria	6.7	4.6	3.7	6.0	15.0	3.9	0.1	0.1	0.3	1.0	0.0	0.1	25.7	15.7
Portugal	4.3	1.8	2.4	1.6	14.0	49.3	0.7	5.6	0.7	0.6	0.0	0.3	22.1	59.1
Sweden	11.6	6.9	4.2	7.1	7.9	5.6	0.0	0.1	0.3	1.4	0.0	0.4	24.0	21.4
Finland	5.2	4.4	1.1	IE	5.8	IE	0.0	0.0	0.2	2.3	0.0	6.4	12.4	13.1
United Kingdom	42.9	50.5	17.2	35.8	18.9	36.4	3.9	4.1	3.8	13.5	0.0	0.5	86.7	140.8
Cyprus	0.3	1.0	0.1	0.7	1.6	8.9	0.1	0.2	0.1	0.8	0.0	0.0	2.2	11.6
Czech Republic	3.8	8.0	2.4	5.1	6.9	9.4	0.0	0.0	0.7	2.0	0.0	0.0	13.8	24.6
Estonia	1.1	1.1	0.4	0.5	0.6	1.1	0.0	0.0	0.1	0.2	0.0	0.0	2.2	2.8
Hungary	2.3	2.2	0.5	0.8	8.3	47.7	0.2	0.3	1.1	6.0	0.0	0.2	12.4	57.3
Lithuania	5.5	6.0	0.8	2.1	1.4	18.5	0.0	0.0	0.2	0.7	0.0	0.1	7.8	27.3
Latvia	1.4	1.1	0.2	0.7	0.5	1.7	0.0	0.0	0.0	0.3	0.0	0.0	2.1	3.9
Malta	0.0	0.3	0.0	0.2	0.2	0.8	0.0	0.0	0.0	0.2	0.0	0.0	0.3	1.5
Poland	23.5	25.9	4.9	15.2	27.8	111.0	0.1	0.1	3.0	10.2	0.0	0.4	59.3	162.8
Slovenia	2.1	6.4	1.6	5.9	0.6	7.7	0.0	0.0	0.1	0.3	0.0	0.0	4.4	20.3
Slovakia	2.7	0.9	1.0	1.2	2.1	4.6	0.1	0.1	0.3	1.1	0.0	0.0	6.2	7.8
Bulgaria	3.6	7.0	0.7	4.3	1.4	7.1	0.5	0.6	0.3	2.4	0.0	0.5	6.5	21.9
Romania	13.1	29.8	4.6	15.7	7.3	45.5	1.4	1.3	1.5	1.6	0.0	1.7	27.9	95.5
EU-27	*435.2*	*496.7*	*195.6*	*588.3*	*623.9*	*1164.9*	*20.3*	*28.5*	*30.7*	*109.8*	*0.0*	*24.2*	*1305.8*	*2412.5*

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories, 3) "Other cattle" in National Inventories included in "Other animals", 4) "Other cattle" in National Inventories included in "Dairy cows"

5.4. Direct N_2O-emissions from grazing animals

N_2O emission factors and total emissions from grazing animals are presented in Table 5.8 and Table 5.9. According to CAPRI total EU-27-emissions for the year 2004 amount to 87 thousand tons, which is 8% less than in national inventory submissions. Differences can be due to livestock numbers (see Table 4.4), assumptions on the share of manure falling on pastures (see Table 5.2), on manure output per head (see Table 2.2), and on the loss factor (LF_{GRAZ}). The loss factor, however, is usually the same as in the National Inventories taking into account the correction due to the mass flow approach (see 4.2.3.1). The largest part of deviations comes from sheep and goat activities, where member states usually do not use the lower loss factor of 1%, as proposed by the IPCC (IPCC, 2006).

Table 5.8: Emission factors for N_2O emissions from grazing in kg per head and year (annual average population for 2004)

	Dairy cows		Other cows		Sheep and goats	
	CAPRI	NI[2]	CAPRI	NI[2]	CAPRI	NI[2]
Belgium[1]	1.32	1.46	0.78	0.80	0.08	0.17
Denmark	1.06	0.44	0.82	0.40	0.12	0.39
Germany	0.23	0.52	0.19	0.25	0.06	0.17
Greece	1.39	0.18	0.77	0.52	0.13	0.38
Spain	0.00	0.00	1.57	0.87	0.11	0.13
France	1.07	1.48	1.17	0.92	0.1	0.35
Ireland	1.83	1.54	1.13	1.20	0.08	0.18
Italy	0.34	0.18	0.08	0.04	0.11	0.46
Netherlands	1.57	0.76	0.49	0.43	0.06	0.13
Austria	0.64	0.14	0.72	0.11	0.04	0.20
Portugal	1.28	0.97	1.34	1.36	0.12	0.17
Sweden	1.34	0.82	0.99	0.47	0.08	0.08
Finland[3]	0.68	0.98	0.39	0.00	0.04	0.10
United Kingdom	1.98	1.47	1.02	0.68	0.12	0.14
Cyprus[4]	1.9	0.00	0.7	0.00	0.15	0.88
Czech Republic	1.49	0.60	0.47	0.84	0.06	0.57
Estonia	1.4	0.37	0.62	0.00	0.09	0.39
Hungary	2.12	0.27	0.9	0.22	0.1	0.25
Lithuania	1.42	1.11	0.64	0.31	0.09	0.42
Latvia	1.58	0.91	1.05	0.73	0.09	0.08
Malta	0.49	0.00	0.84	0.00	0.05	0.00
Poland	0.62	0.30	0.24	0.17	0.08	0.08
Slovenia	0.38	0.38	0.21	0.15	0.06	0.42
Slovakia	1.72	0.63	0.69	0.19	0.09	0.28
Bulgaria	1.66	0.29	0.81	0.13	0.13	0.28
Romania	1.36	0.29	0.63	0.41	0.11	0.40

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories, 3) “Other cattle” in National Inventories included in “Other animals”, 4) “Other cattle” in National Inventories included in “Dairy cows”

Table 5.9: N_2O emissions from grazing in 1000 tons for 2004: CAPRI-Values compared to the values reported by the member states (National Inventories of 2010 for 2004)

	Dairy cows		Other Cattle		Swine		Sheep and goats		Poultry		Other animals		***Total emission***	
	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	***Capri***	***NI***[2]
Belgium[1]	0.81	0.81	1.44	1.87	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.07	2.25	2.79
Denmark	0.62	0.25	0.73	0.44	0.05	0.02	0.01	0.05	0.00	0.00	0.00	0.12	1.41	0.82
Germany	0.99	2.25	1.39	2.22	0.00	0.00	0.13	0.47	0.00	0.00	0.00	0.40	2.51	5.36
Greece	0.21	0.04	0.33	0.20	0.00	0.00	1.50	5.43	0.00	0.41	0.00	0.13	2.04	6.21
Spain	0.00	0.00	9.74	4.80	1.61	0.00	2.58	3.37	0.00	0.00	0.00	0.21	13.93	8.38
France	4.22	5.93	15.91	14.17	0.00	0.02	0.99	3.71	0.00	0.10	0.00	0.23	21.11	24.15
Ireland	2.08	1.75	5.07	6.09	0.00	0.00	0.35	1.20	0.00	0.00	0.00	0.07	7.51	9.11
Italy	0.69	0.34	0.43	0.18	0.00	0.00	0.82	4.16	0.00	0.00	0.00	0.31	1.94	4.98
Netherlands	2.38	1.12	0.79	0.98	0.00	0.00	0.09	0.19	0.00	0.00	0.00	0.09	3.25	2.19
Austria	0.35	0.07	1.00	0.17	0.00	0.00	0.01	0.08	0.00	0.00	0.00	0.03	1.37	0.36
Portugal	0.42	0.33	1.49	1.46	0.02	0.03	0.30	0.66	0.00	0.01	0.00	0.05	2.22	2.53
Sweden	0.54	0.33	0.96	0.58	0.00	0.00	0.02	0.04	0.00	0.00	0.00	0.18	1.52	1.09
Finland	0.22	0.32	0.22	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.04	0.44	0.56
United Kingdom	4.18	3.13	7.15	5.74	0.04	0.11	2.41	4.88	0.00	0.17	0.00	0.40	13.78	14.43
Cyprus	0.05	0.00	0.02	0.00	0.00	0.00	0.07	0.58	0.00	0.00	0.00	0.00	0.14	0.58
Czech Republic	0.62	0.34	0.34	0.71	0.00	0.00	0.01	0.07	0.00	0.01	0.00	0.02	0.97	1.15
Estonia	0.16	0.04	0.07	0.00	0.00	0.04	0.00	0.02	0.00	0.00	0.00	0.01	0.23	0.10
Hungary	0.62	0.09	0.27	0.09	0.00	0.00	0.11	0.37	0.00	0.00	0.00	0.05	1.00	0.59
Lithuania	0.60	0.48	0.21	0.11	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.05	0.82	0.66
Latvia	0.27	0.17	0.14	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.41	0.32
Malta	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Poland	1.59	0.84	0.50	0.43	0.00	0.00	0.03	0.04	0.00	0.00	0.00	0.03	2.11	1.33
Slovenia	0.05	0.05	0.06	0.05	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.01	0.11	0.16
Slovakia	0.27	0.15	0.15	0.06	0.00	0.00	0.03	0.10	0.00	0.00	0.00	0.01	0.44	0.31
Bulgaria	0.60	0.10	0.28	0.04	0.00	0.03	0.33	0.67	0.00	0.02	0.00	0.00	1.22	1.73
Romania	2.03	0.45	1.15	0.49	0.00	0.00	0.79	3.20	0.00	0.02	0.00	0.65	3.97	4.80
EU-27	*24.55*	*19.36*	*49.86*	*41.01*	*1.73*	*0.25*	*10.60*	*29.42*	*0.00*	*0.75*	*0.00*	*3.20*	*86.74*	*94.72*

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories, 3) "Other cattle" in National Inventories included in "Other animals", 4) "Other cattle" in National Inventories included in "Dairy cows"

5.5. Direct N_2O-emissions from manure management

N_2O-emissions from manure management for the EU-27, according to CAPRI, amount to 97 thousand tons, which is around 7% less than what is estimated by the member states. The total match, therefore, is satisfactory. However, considerably lower numbers for dairy and cattle production are compensated by higher numbers in pig production. Emission factors and total emissions are presented in Table 5.10 and Table 5.11.Due to the different approaches deviating results are expectable. First, the distribution of manure management systems is taken from different data sources, and is, therefore, subject to considerable differences (see Table 4.6). Furthermore, CAPRI uses the (corrected) default N_2O-loss factors (0.71/0.91% for solid and 0.83/0.96% for liquid systems) recommended in the IPCC 2006 guidelines (IPCC, 2006), while the national inventories are mainly based on the IPCC 2001 (IPCC, 2000) values (2% for solid systems and 0.1% for liquid). The correction of the loss factors due to the mass flow approach (see Section

4.2.3.2) leads to further deviations, since the NH_3 and NO_x emission factors of CAPRI are not those of the IPCC guidelines used for the correction of the N_2O-emission factors. The consideration of emission reduction measures in CAPRI (see Section 4.2.3.2) has positive and negative effects on N_2O-emissions. In case of measures which reduce N_2O-emissions the effect is, in general, negative. If, however, a reduction measure reduces only NH_3- or NO_x-emissions, N_2O-emissions could also be increased compared to a calculation without reduction measures. In contrast, national inventories, as the IPCC standard approach, do not specifically take reduction measures into account. Finally, livestock numbers (Table 5.1), nitrogen excretion (Table 5.2) and, due to the mass flow approach, the share of manure falling on pastures (see Table 4.4) impact on the final emission numbers, and have to be taken into account in explaining deviations in the results for specific countries or animal categories.

Table 5.10: Emission factors for N_2O emissions from manure management (housing and storage) in kg per head and year (annual average population for 2004)

	Dairy cows		Other cows		Swine		Sheep and goats		Poultry[5]	
	[kg head^{-1} yr^{-1}]								[kg (1000 head)$^{-1}$ yr^{-1}]	
	CAPRI	NI[2]	CAPRI	NI[2]	CAPRI	NI[2]	CAPRI	NI[2]	CAPRI	NI[2]
Belgium[1]	0.60	0.98	0.32	0.64	0.50	0.04	0.02	0.07	22.93	11.87
Denmark	1.90	0.49	0.49	0.51	0.92	0.03	0.03	0.14	8.03	22.81
Germany	1.17	0.67	0.42	0.21	0.52	0.06	0.02	0.02	4.97	6.16
Greece	0.62	1.98	0.31	0.98	0.28	0.07	0.01	0.00	8.48	1.32
Spain	1.09	1.29	0.08	0.61	0.28	0.10	0.01	0.02	10.33	4.69
France	0.77	1.35	0.24	0.55	0.21	0.11	0.03	0.25	5.88	6.72
Ireland	0.42	0.13	0.23	0.16	0.18	0.01	0.01	0.02	4.77	9.13
Italy	0.95	2.15	0.45	0.70	0.25	0.02	0.01	0.05	6.13	15.82
Netherlands	0.91	0.16	0.28	0.12	1.41	0.01	0.01	0.09	41.83	18.97
Austria	0.76	1.80	0.25	0.90	0.22	0.07	0.04	0.20	4.63	15.16
Portugal	0.88	1.51	0.37	0.09	0.24	0.02	0.02	0.02	6.10	11.80
Sweden	1.53	1.14	0.41	0.53	0.46	0.08	0.05	0.10	7.03	9.48
Finland[3]	0.78	0.99	0.24	0.00	0.16	0.00	0.02	0.20	4.10	16.52
United Kingdom	0.91	0.46	0.31	0.35	0.20	0.21	0.00	0.00	9.45	11.88
Cyprus[4]	0.87	2.20	0.28	1.57	0.26	0.35	0.01	0.00	5.53	18.86
Czech Republic	0.73	0.70	0.37	0.19	0.25	0.17	0.01	0.03	4.29	4.27
Estonia	0.84	1.92	0.30	0.55	0.22	0.18	0.01	0.13	4.46	13.41
Hungary	0.89	3.03	0.32	1.21	0.33	0.07	0.02	0.37	5.29	14.19
Lithuania	0.64	1.34	0.25	1.02	0.22	0.17	0.01	0.01	4.69	1.88
Latvia	0.94	1.19	0.35	0.78	0.30	0.17	0.05	0.11	6.37	11.87
Malta	1.39	0.00	0.35	0.00	0.30	0.00	0.07	0.00	5.93	0.00
Poland	0.73	2.25	0.35	1.43	0.19	0.31	0.01	0.14	4.89	8.88
Slovenia	0.80	1.37	0.39	0.55	0.17	0.15	0.01	0.24	2.49	14.96
Slovakia	0.77	0.21	0.28	0.14	0.22	0.01	0.02	0.02	4.80	96.06
Bulgaria	0.71	1.48	0.33	0.88	0.26	0.15	0.02	0.02	5.28	7.43
Romania	0.59	1.52	0.26	0.16	0.24	0.38	0.02	0.02	4.45	2.74

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories, 3) “Other cattle” in National Inventories included in “Other animals”, 4) “Other cattle” in National Inventories included in “Dairy cows”, 5) kg per 1000 heads

Table 5.11: N_2O emissions from manure management (housing and storage) in 1000 tons for 2004: CAPRI-Values compared to those reported by the member states (National Inventories of 2010 for 2004)

	Dairy cows		Other Cattle		Swine		Sheep and goats		Poultry		Other animals		***Total emission***	
	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	Capri	NI[2]	***Capri***	***NI***[2]
Belgium[1]	0.37	0.54	0.59	1.49	2.52	0.28	0.00	0.01	0.60	0.39	0.00	0.02	4.08	2.74
Denmark	1.10	0.28	0.44	0.55	7.10	0.40	0.00	0.02	0.18	0.38	0.00	0.16	8.82	1.79
Germany	5.06	2.86	3.13	1.88	10.59	1.48	0.03	0.06	0.71	0.76	0.00	0.23	19.53	7.26
Greece	0.09	0.44	0.13	0.39	0.15	0.07	0.15	0.00	0.24	0.04	0.00	0.00	0.77	0.93
Spain	1.20	1.38	0.51	3.36	3.82	2.41	0.14	0.61	1.75	0.74	0.00	0.54	7.42	9.03
France	3.02	5.41	3.30	8.44	2.01	1.26	0.26	2.61	1.36	1.79	0.00	0.14	9.95	19.65
Ireland	0.48	0.14	1.02	0.82	0.17	0.02	0.05	0.11	0.07	0.15	0.00	0.04	1.78	1.29
Italy	1.93	3.95	2.48	3.12	1.89	0.16	0.05	0.46	0.89	3.03	0.00	1.26	7.24	11.98
Netherlands	1.38	0.24	0.44	0.28	9.04	0.15	0.02	0.14	3.11	1.68	0.00	0.11	13.99	2.60
Austria	0.42	0.97	0.35	1.36	0.51	0.23	0.01	0.08	0.07	0.20	0.00	0.11	1.36	2.94
Portugal	0.29	0.51	0.41	0.09	0.34	0.05	0.05	0.07	0.20	0.39	0.00	0.15	1.29	1.25
Sweden	0.61	0.46	0.40	0.65	0.56	0.15	0.01	0.05	0.10	0.16	0.00	0.22	1.68	1.70
Finland	0.25	0.32	0.14	0.00	0.14	0.00	0.00	0.02	0.04	0.17	0.00	0.85	0.58	1.36
United Kingdom	1.92	0.98	2.21	2.94	0.58	1.07	0.06	0.13	1.71	2.06	0.00	0.02	6.48	7.19
Cyprus	0.02	0.05	0.01	0.05	0.06	0.16	0.01	0.00	0.02	0.06	0.00	0.00	0.13	0.33
Czech Republic	0.30	0.40	0.27	0.16	0.54	0.53	0.00	0.00	0.14	0.11	0.00	0.00	1.25	1.20
Estonia	0.09	0.22	0.04	0.07	0.04	0.06	0.00	0.01	0.01	0.03	0.00	0.00	0.18	0.40
Hungary	0.26	0.94	0.10	0.51	0.85	0.33	0.03	0.54	0.24	0.72	0.00	0.20	1.48	3.24
Lithuania	0.27	0.58	0.08	0.36	0.10	0.18	0.00	0.00	0.03	0.02	0.00	0.00	0.48	1.14
Latvia	0.16	0.22	0.05	0.15	0.05	0.07	0.00	0.01	0.01	0.05	0.00	0.01	0.26	0.51
Malta	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.03	0.02
Poland	1.87	6.29	0.72	3.64	1.65	5.27	0.00	0.07	0.61	1.16	0.00	0.25	4.85	16.68
Slovenia	0.10	0.18	0.11	0.17	0.03	0.08	0.00	0.03	0.02	0.05	0.00	0.01	0.26	0.53
Slovakia	0.12	0.05	0.06	0.04	0.14	0.01	0.00	0.01	0.06	1.32	0.00	0.00	0.39	1.43
Bulgaria	0.26	0.54	0.12	0.29	0.11	0.15	0.05	0.04	0.07	0.15	0.00	0.33	0.60	1.50
Romania	0.88	2.37	0.46	0.19	0.52	2.47	0.13	0.19	0.25	0.24	0.00	0.02	2.25	5.48
EU-27	*22.49*	*30.33*	*17.56*	*31.02*	*43.52*	*17.05*	*1.08*	*5.26*	*12.48*	*15.83*	*0.00*	*4.68*	*97.12*	*104.17*

Sources: EEA, 2008, own calculations; 1) Luxemburg included, 2) NI=National Inventories, 3) "Other cattle" in National Inventories included in "Other animals", 4) "Other cattle" in National Inventories included in "Dairy cows"

5.6. Direct N_2O-emissions from manure application to agricultural soils

For N_2O-emissions from manure application to managed soils a direct comparison of emission factors (emissions per head of animal) between inventories and CAPRI is not possible, because inventories do not differentiate between animal categories. Total emissions of EU-27, according to CAPRI results, amount to 88 thousand tons, which is 19% below the value submitted by the member states (see Table 5.12). With respect to the different approaches the level of correspondence is satisfactory. The sources of deviations are more or less those already mentioned in the preceding section. The loss factor (emissions per kg N) applied in the inventories is generally 1.25%, which corresponds to the default value suggested in the 1996 IPCC guidelines (IPCC, 1997). CAPRI applies the same loss factor being equivalent to the corrected default factor of the IPCC 2006 guidelines (see Section 4.2.3.3). However, in contrast to the inventories CAPRI

considers emission reduction measures, which, while reducing NH_3- and NO_x-emissions, tend to increase emissions of N_2O (see

Table 4.13). This is reflected by larger values for countries with high frequencies of reduction measures, like Denmark.

Table 5.12: N_2O emissions from manure application to managed soils in 1000 tons for 2004: CAPRI-Values compared to those reported by the member states (National Inventories of 2010 for 2004)

	Dairy cows	Other Cattle	Swine	Sheep and goats	Poultry	***Total emission***	
	Capri					***Capri***	***NI***[2]
Belgium[1]	0.59	0.80	1.80	0.00	0.24	3.44	2.8
Denmark	2.01	0.72	2.98	0.01	0.35	6.06	3.6
Germany	6.76	3.62	7.00	0.04	1.39	18.81	19.6
Greece	0.10	0.12	0.10	0.16	0.16	0.64	0.7
Spain	1.23	0.42	2.22	0.15	1.04	5.07	6.6
France	3.20	3.00	2.12	0.29	1.39	10.00	17.0
Ireland	0.52	1.05	0.20	0.06	0.08	1.90	1.5
Italy	2.44	2.36	1.83	0.05	0.86	7.54	8.6
Netherlands	3.01	0.83	2.48	0.02	0.80	7.13	8.8
Austria	0.50	0.35	0.53	0.02	0.08	1.49	2.2
Portugal	0.30	0.34	0.29	0.05	0.20	1.19	1.0
Sweden	0.82	0.47	0.39	0.01	0.14	1.84	2.5
Finland	0.39	0.18	0.20	0.00	0.06	0.83	1.2
United Kingdom	2.27	2.39	0.59	0.06	1.25	6.55	7.9
Cyprus	0.02	0.01	0.06	0.01	0.02	0.12	0.1
Czech Republic	0.36	0.26	0.54	0.00	0.16	1.32	2.5
Estonia	0.10	0.03	0.03	0.00	0.01	0.17	0.3
Hungary	0.27	0.08	1.25	0.04	0.30	1.94	2.2
Lithuania	0.27	0.08	0.08	0.00	0.04	0.47	1.0
Latvia	0.16	0.04	0.04	0.00	0.01	0.25	0.3
Malta	0.01	0.00	0.01	0.00	0.01	0.03	0.0
Poland	3.18	0.98	2.06	0.01	1.14	7.36	10.1
Slovenia	0.12	0.12	0.03	0.00	0.02	0.28	0.5
Slovakia	0.12	0.05	0.12	0.01	0.08	0.38	0.9
Bulgaria	0.25	0.09	0.08	0.08	0.08	0.58	0.9
Romania	0.87	0.40	0.44	0.19	0.30	2.20	5.6
EU-27	*29.88*	*18.78*	*27.46*	*1.27*	*10.21*	*87.59*	*108.46*

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories

5.7. Direct N_2O-emissions from the application of mineral fertilizers

Emissions from the application of mineral fertilizers are not directly caused by animal activities, but due to the high share of crop products used as feed stuff a large part of crop's emissions have to be allocated to livestock in a life cycle approach. Therefore, crop emissions are also considered in this study. As in the case of emissions from manure application a comparison is only possible on the level of total emissions since crop specific emissions are not provided in the national inventories. According to CAPRI calculations, total N_2O-emissions of the EU-27 amounts to 181 thousand tons, which is 11% less than in the national inventories. On country level the correspondence is generally

good, only for some countries like Italy, Portugal, Sweden, Czech Republic, Malta and Slovenia deviations are somewhat higher. The overwhelming part of mineral fertilizers is applied to cereals and grassland, while other fodder crops, like fodder maize or pulses receive only a small share (see Table 5.3). This leads directly to the emission shares, since CAPRI does not differentiate the loss factor by crops. The deviations are in first line related to the different loss factors applied by the national inventories on the one hand, and CAPRI on the other hand. While CAPRI uses the corrected default value of the IPCC guidelines 2006 1.11% (see Section 4.2.4), national inventories are generally based on the 1996 default value (IPCC, 1997) of 1.25%, which partly explains the higher emissions there. In some countries deviations are also due to different assumptions on fertilizer application (see Table 5.3), although in general the correspondence is high.

Table 5.13: N_2O emissions from application of mineral fertilizers for 2004: CAPRI-Values compared to those reported by the member states (National Inventories of 2010 for 2004) in 1000 t

	CAPRI								*NI[1]*
	Cereals	*Pulses*	*Oilseeds*	*Grassland*	*Fodder Maize*	*Other feed cops*	*Other crops*	*Total*	*Total*
Belgium	1.14	0.00	0.05	0.87	0.02	0.02	0.67	2.77	3.21
Denmark	2.20	0.00	0.44	0.20	0.05	0.29	0.27	3.45	3.99
Germany	16.93	0.07	5.08	3.92	1.28	0.22	2.57	30.06	35.90
Greece	1.92	0.01	0.01	0.56	0.00	0.01	1.43	3.93	4.51
Spain	6.58	0.08	0.37	4.09	0.01	0.01	5.48	16.61	19.27
France	22.51	0.53	5.41	5.43	0.82	0.15	2.93	37.77	41.43
Ireland	0.62	0.00	0.01	3.44	0.02	1.62	0.15	5.86	7.01
Italy	5.81	0.01	0.13	1.30	0.24	0.01	3.64	11.14	15.03
Netherlands	0.75	0.00	0.01	1.49	0.15	0.29	1.91	4.60	4.69
Austria	1.04	0.01	0.08	0.37	0.01	0.06	0.16	1.74	1.86
Portugal	0.31	0.00	0.00	0.64	0.02	0.01	0.48	1.46	2.33
Sweden	1.54	0.00	0.02	0.20	0.02	0.99	0.19	2.96	2.20
Finland	1.98	0.00	0.15	0.44	0.00	0.02	0.17	2.76	2.99
United Kingdom	8.38	0.02	0.38	6.93	0.11	1.35	1.05	18.21	21.79
Cyprus	0.07	0.00	0.00	0.00	0.00	0.03	0.05	0.15	0.14
Czech Republic	2.66	0.01	1.12	0.37	0.43	0.01	0.29	4.88	3.83
Estonia	0.26	0.00	0.06	0.11	0.00	0.03	0.03	0.49	0.44
Hungary	4.02	0.03	0.85	0.28	0.01	0.00	0.47	5.65	5.18
Lithuania	1.05	0.01	0.00	0.50	0.03	0.11	0.20	1.90	2.17
Latvia	0.30	0.00	0.00	0.20	0.00	0.00	0.11	0.62	0.62
Malta	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.01
Poland	10.16	0.06	1.38	1.25	0.09	0.27	1.97	15.18	15.82
Slovenia	0.35	0.00	0.02	0.39	0.19	0.01	0.09	1.05	0.54
Slovakia	0.88	0.01	0.28	0.07	0.15	0.02	0.11	1.52	1.41
Bulgaria	1.55	0.01	0.44	0.00	0.03	0.02	0.25	2.29	2.92
Romania	2.72	0.02	0.22	0.01	0.01	0.14	0.71	3.82	4.77
EU-27	*95.73*	*0.88*	*16.50*	*33.05*	*3.68*	*5.68*	*25.36*	*180.89*	*204.05*

Sources: EEA, 2010, own calculations; 1) NI=National Inventories

5.8. Direct N_2O-emissions from crop residues, including N-fixing crops

According to the IPCC Guidelines 1996 (IPCC, 1997) N_2O-emissions from crop residues and N-fixation were calculated separately, using a default loss factor of 1.25%. This approach is generally applied in the national inventories. CAPRI, in contrast, follows the IPCC Guidelines 2006 (IPCC, 2006), and, therefore, uses a loss factor of 1%. Moreover, following the new Guidelines, emissions of N-fixation are not calculated any more due to lack of evidence of significant emissions arising from the fixation process itself. Total EU-27 emissions from crop residues amount to 85 thousand tons respectively, compared to 77 thousand tons according to member state results. If emissions from N-fixation are included, the number, according to inventories, increases to 98 thousand tons (see Table 5.14).

Table 5.14: N_2O emissions from crop residues for 2004: CAPRI-Values compared to those reported by the member states (National Inventories of 2010 for 2004) in 1000 t

	CAPRI								*NI[1]*		
	Cereals	*Pulses*	*Oilseeds*	*Grassland*	*Fodder Maize*	*Other feed cops*	*Other crops*	*Total*	*Crop residues*	*Biological Fixation*	*Total*
Belgium	0.18	0.00	0.02	0.48	0.09	0.17	0.38	1.32	1.49	0.11	1.60
Denmark	0.54	0.01	0.11	0.14	0.05	0.55	0.16	1.56	1.05	0.59	1.64
Germany	3.16	0.07	1.38	3.87	0.56	0.64	1.54	11.21	22.76	1.80	24.56
Greece	0.44	0.00	0.00	0.20	0.00	0.06	0.39	1.10	0.51	0.02	0.53
Spain	1.48	0.05	0.14	2.56	0.04	0.43	1.37	6.07	2.75	3.69	6.44
France	5.25	0.32	1.55	4.65	0.60	3.03	1.89	17.28	9.77	7.49	17.26
Ireland	0.13	0.00	0.00	2.52	0.01	1.41	0.08	4.15	0.46	0.01	0.47
Italy	2.05	0.21	0.06	1.07	0.14	0.87	1.32	5.72	2.81	3.39	6.20
Netherlands	0.12	0.00	0.00	0.80	0.11	0.38	0.68	2.10	0.52	0.08	0.59
Austria	0.51	0.04	0.05	0.87	0.04	0.12	0.17	1.78	0.95	0.40	1.36
Portugal	0.13	0.00	0.00	0.45	0.02	0.17	0.14	0.92	0.47	0.05	0.52
Sweden	0.34	0.01	0.06	0.25	0.00	1.01	0.15	1.81	1.07	0.65	1.72
Finland	0.25	0.00	0.03	0.21	0.00	0.01	0.07	0.58	0.45	0.01	0.46
United Kingdom	1.25	0.12	0.54	6.27	0.04	1.53	0.60	10.34	8.49	0.72	9.20
Cyprus	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.00	0.04
Czech Republic	0.44	0.02	0.24	0.35	0.06	0.15	0.18	1.44	2.91	0.12	3.03
Estonia	0.04	0.00	0.02	0.12	0.00	0.17	0.01	0.36	0.18	0.00	0.18
Hungary	1.48	0.03	0.31	0.40	0.03	0.17	0.22	2.64	2.70	0.43	3.13
Lithuania	0.16	0.01	0.05	0.47	0.00	0.26	0.06	1.01	0.80	0.07	0.87
Latvia	0.06	0.00	0.02	0.25	0.00	0.23	0.04	0.60	0.11	0.00	0.11
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NE	NE	0.00
Poland	1.87	0.03	0.35	1.43	0.11	0.35	0.83	4.97	4.57	0.40	4.97
Slovenia	0.06	0.00	0.00	0.12	0.01	0.00	0.02	0.22	0.10	0.03	0.13
Slovakia	0.26	0.01	0.10	0.21	0.02	0.10	0.07	0.77	1.31	0.28	1.59
Bulgaria	0.48	0.00	0.22	0.57	0.00	0.06	0.07	1.40	0.83	0.01	0.84
Romania	2.21	0.12	0.36	2.33	0.01	0.62	0.25	5.90	9.72	0.41	10.13
EU-27	*22.90*	*1.06*	*5.60*	*30.59*	*1.93*	*12.50*	*10.69*	*85.27*	*76.82*	*20.77*	*97.59*

Sources: EEA, 2010, own calculations; 1) NI=National Inventories

Therefore, depending on whether taking N-fixation into account or not, CAPRI results are 11% above or 13% below member state results. While correspondence on EU-level is high, on country

level deviations are considerably larger, ranging from -50% in Germany to +800% in Ireland. The deviations are supposed to be due to different assumptions on Crop Residue/Crop Product ratios, nitrogen fractions and yield assumptions of crop products, which, however, are not transparently documented in the national submissions. Finally, according to CAPRI, 36% of the emissions are related to grasslands, 27% to cereals, and another 17% to other feed crops. This implies that a large share of emissions from crop residues can be assigned to livestock.

5.9. Indirect N_2O-emissions following N-deposition of volatilized NH_3/NO_x

In CAPRI indirect N_2O-emissions following N-deposition of volatilized NH_3 and NO_X are calculated as 1% (default loss factor of IPCC Guidelines 2006) of all NH_3- and NO_X-emissions, explicitly quantified in each stage of the production process (see Section 4.2.3). In contrast, national inventories generally use only two factors, one for mineral fertilizers and one for manure, in order to determine the fraction that volatilizes as NH_3 and NO_X. The factors are applied to total nitrogen excretion and mineral fertilizer application respectively, which have been presented in preceding sections (see Table 5.2 and Table 5.3). Most countries use the default IPCC factors of the 1996 Guidelines (10% for mineral fertilizers, 20% for manure), some countries use other factors (see Table 5.15). From this 1% is assumed to be emitted as N_2O, which corresponds to the loss factor applied in CAPRI.

According to CAPRI all member states emitted 42 thousand tons in total, which is 11% less than what is estimated by the national inventories (see Table 5.16). Considering the different approaches the level of correspondence is satisfactory, not only on EU level but also on the level of member states.

Table 5.15: Loss factors of N volatilizing as NH_3 and NO_X for mineral fertilizer and manure used by the National Inventories (Submission 2010 for 2004)

	Mineral Fertilizer	Manure
Belgium	0.03	0.21
Denmark	0.02	0.20
Germany	0.05	0.29
Greece	0.10	0.20
Spain	0.06	0.20
France	0.10	0.20
Ireland	0.02	0.19
Italy	0.09	0.29
Netherlands	0.04	0.19
Austria	0.03	0.27
Portugal	0.06	0.20
Sweden	0.01	0.33
Finland	0.01	0.25
United Kingdom	0.10	0.20
Cyprus[4]	0.10	0.20
Czech Republic	0.10	0.20
Estonia	0.10	0.20
Hungary	0.10	0.20
Lithuania	0.10	0.20
Latvia	0.10	0.20
Malta	NE	NE
Poland	0.10	0.20
Slovenia	0.10	0.20
Slovakia	0.10	0.24
Bulgaria	0.10	0.20
Romania	0.10	0.20

Sources: EEA, 2010, NE: Not available

Table 5.16: N_2O emissions following N-deposition of volatilized NH_3/NO_x in 1000 tons for 2004: CAPRI-Values compared to those reported by the member states (National Inventories of 2010 for 2004)

	Total emissions	
	CAPRI	NI[2]
Belgium[1]	0.9	1.0
Denmark	1.4	1.0
Germany	6.1	7.8
Greece	0.5	1.2
Spain	4.4	3.1
France	7.2	9.5
Ireland	1.1	1.4
Italy	4.5	5.2
Netherlands	1.3	1.6
Austria	0.7	0.8
Portugal	0.8	0.6
Sweden	0.7	0.6
Finland	0.3	0.5
United Kingdom	3.5	5.3
Cyprus	0.1	NE
Czech Republic	0.8	1.0
Estonia	0.1	0.1
Hungary	0.9	1.0
Lithuania	0.4	0.5
Latvia	0.2	0.2
Malta	0.0	NE
Poland	3.5	1.6
Slovenia	0.2	0.2
Slovakia	0.3	0.4
Bulgaria	0.4	0.7
Romania	1.5	2.0
EU-27	*41.8*	*46.90*

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories

5.10. Indirect N_2O-emissions following Leaching and Runoff

Indirect N_2O-emissions from Leaching and Runoff amount to 23 thousand tons according to CAPRI, which is only 11% of the value calculated by the member states (see Table 5.18). The deviations result from big differences in the calculation approach. On the one hand this is due to changes in the IPCC Guidelines from 1996 to 2006. In the 1996 Guidelines (IPCC, 1997) a general leaching factor of 30% shall be applied to the whole nitrogen excreted by animals or applied as mineral fertilizer in order to estimate nitrogen leaching. Then a general loss factor of 2.5% has to be applied to the leached nitrogen in order to estimate the N_2O-emissions from leached nitrogen. This approach is generally followed by the National Inventories even if some countries use different Leaching factors (see Table 5.17). According to the 2006 Guidelines (see IPCC 2006, Vol. 4, Ch.11, Table 11.3) the leaching factor (30%) should only be applied to those regions where leaching or runoff occurs, which is defined by potential evaporation and rainfall. For all other regions it is supposed to be zero. Moreover, the N_2O-loss factor applied to leached nitrogen was reduced from 2.5% to 0.75% (see IPCC 2006, Vol. 4, Ch.11, Table 11.3), further reducing N_2O-emissions.

CAPRI follows the MITERRA-approach (see Section 4.2.7), which, in contrast to the IPCC approach, does not apply a general leaching factor to the whole excreted manure and applied mineral fertilizer. In contrast, superficial runoff and leaching below soils is generally separated, and both leaching and runoff factors are defined on a regional level (see Annex to Chapter 4, Table A1). Superficial runoff is calculated on several stages of the production process. First runoff from housing and storage is calculated for nitrate vulnerable zones only, and based on the manure excreted in housing systems. Secondly, runoff from soils is based on manure and mineral fertilizer applied on fields or deposited by grazing animals, already corrected by gaseous emissions. Thirdly, the leaching factor is applied to the nitrogen surplus, which is the balance between all nitrogen inputs and nitrogen outputs (including emissions) of the agricultural system. Finally, the default loss factor of IPCC 2006 of 0.75% is applied to all the nitrogen subject to runoff and leaching in order to derive N_2O-emissions.

Table 5.17: Loss factors of N volatilizing as NH_3 and NO_X for mineral fertilizer and manure used by the National Inventories (Submission 2010 for 2004)

	Leaching Factor
Belgium[1]	0.14
Denmark	0.33
Germany	0.30
Greece	0.30
Spain	0.30
France	0.30
Ireland	0.10
Italy	0.30
Netherlands	0.30
Austria	0.30
Portugal	0.33
Sweden	0.24
Finland	0.15
United Kingdom	0.30
Cyprus[4]	0.00
Czech Republic	0.30
Estonia	0.30
Hungary	0.30
Lithuania	0.30
Latvia	0.30
Malta	NE
Poland	0.30
Slovenia	0.30
Slovakia	0.14
Bulgaria	0.20
Romania	0.30

Sources: EEA, 2010, NE: Not available, 1) Luxemburg included

Table 5.18: N_2O emissions following Leaching and Runoff in 1000 tons for 2004: CAPRI-Values compared to those reported by the member states (National Inventories of 2010 for 2004)

	Total emissions	
	CAPRI	NI[2]
Belgium[1]	1.0	2.4
Denmark	1.0	6.3
Germany	2.9	13.4
Greece	0.2	5.9
Spain	2.2	21.3
France	3.8	49.6
Ireland	0.8	2.9
Italy	1.5	19.9
Netherlands	1.4	8.9
Austria	0.1	2.9
Portugal	0.2	3.3
Sweden	0.1	2.7
Finland	0.1	1.4
United Kingdom	2.8	22.8
Cyprus	0.0	NE
Czech Republic	0.7	4.9
Estonia	0.1	0.5
Hungary	0.5	5.3
Lithuania	0.4	2.5
Latvia	0.2	0.8
Malta	0.0	NE
Poland	1.6	11.1
Slovenia	0.1	0.8
Slovakia	0.1	0.9
Bulgaria	0.3	2.3
Romania	0.5	9.2
EU-27	22.8	201.72

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories

5.11. N_2O-emissions from the cultivation of organic soils

The calculation of N_2O-emissions from the cultivation of organic soils in CAPRI is based on the IPCC emission factors which are also applied in the National inventories. However, the assumed national area of organic soils cultivated for agricultural purposes is generally different to the area used by the Inventories, and for many countries inventory values are not even available. Therefore, total emissions partly differ considerably on country level. On EU level total emissions, according to CAPRI calculations, amount to 37 thousand tons which is 97% of the values presented by the member states (38 thousand tons).

Table 5.19: N_2O emissions from the cultivation of organic soils in 1000 tons for 2004: CAPRI-Values compared to those reported by the member states (National Inventories of 2010 for 2004)

	Total emissions	
	CAPRI	NI[2]
Belgium[1]	0.00	0.03
Denmark	0.04	0.35
Germany	10.06	16.38
Greece	0.00	0.08
Spain	0.48	NO
France	4.79	NO
Ireland	0.03	NO
Italy	0.00	0.11
Netherlands	2.64	1.65
Austria	0.05	NO
Portugal	0.01	NO
Sweden	0.00	3.14
Finland	9.91	4.12
United Kingdom	1.29	0.49
Cyprus	0.00	NE
Czech Republic	0.08	NO
Estonia	0.37	0.43
Hungary	1.13	NO
Lithuania	0.17	1.44
Latvia	0.03	0.97
Malta	0.00	NO
Poland	5.81	9.16
Slovenia	0.22	0.09
Slovakia	0.00	NO
Bulgaria	0.00	0.00
Romania	0.06	NO
EU-27	37.17	*38.45*

Sources: EEA, 2010, own calculations; 1) Luxemburg included, 2) NI=National Inventories

5.12. Summary

This chapter gives a short overview of activity based GHG emissions in CAPRI, compared to the official data of the member states provided in the national inventories. For the comparison we selected the latest inventory submission of the year 2010, however not for the latest available year but for the year 2004, the base year selected for the CAPRI calculations.

In some cases results differ substantially between CAPRI and the inventory submissions, which, basically, can be related to three different reasons: First, the approach of CAPRI and the national inventories is not always the same. Second, most countries base their inventory calculations on the IPCC guidelines 1996, while CAPRI uses parameters of the most recent guidelines (2006). Finally, diverging 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.

For EU-27 CAPRI calculates total agricultural sector emissions of 378 Mio tons of CO_{2-eq}, which is 79% of the value reported by the member states (477 Mio tons). 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 National Inventories. With respect to the different emission sources the relation of CAPRI emissions to National Inventory emissions 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 N_2O emissions from the cultivation of organic soils.

6. QUANTIFICATION OF GHG EMISSIONS OF EU LIVESTOCK PRODUCTION IN FORM OF A LIFE CYCLE ASSESSMENT (LCA)

Lead author: Franz Weiss; Contribution: Adrian Leip

6.1. General remarks to the LCA approach

In contrast to the activity based results presented in Chapter 5, emissions caused by livestock production in the EU include emissions from imported inputs and emissions from inputs created in other sectors, like chemical industries or the energy sector. We consider all emissions up to the moment the animal product leaves the farm gate, which means that we do not include emissions from animal transport or the processing and transport of animal products, neither emissions related to their consumption, package, or waste. Emissions are expressed kg of animal product. For the detailed description of the methodology see Chapter 4.

The results presented in this chapter are based on those presented in Chapter 5 but due to the LCA they are not a simple mapping from heads to products and an extension of the sectorial and regional scope. Additional deviations between the total emissions of the two approaches can also occur due the fact that the LCA approach considers young animals inputs rather than final animal products. 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 fattening activity. So, in contrast to the activity based approach, for the calculation of 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 to be expected.

Quantified emissions sources and sinks for the greenhouse gases CH_4, N_2O and CO_2, and the nitrogen gases NH_3 and NO_X are given in Table 4.1. For some of the emissions sources (manufacturing and application of mineral fertilizers) the emissions can become negative, since due to the accounting principles (see Section 4.4) emissions from the application of manure will be accounted for animals but corrected by a reduction of emissions from mineral fertilizers to the extent that mineral fertilizers were substituted by manure. If, therefore, the emissions related to the application and manufacturing of mineral fertilizers for feed production are lower than the emissions saved by the application of manure for non-feed-related uses, the sum of the two values can become negative.

6.2. Cow milk and beef production

According to CAPRI-calculations, in the EU-27 384 Mio tons of $CO_{2\text{-eq}}$ are, directly and indirectly, emitted by the dairy and cattle sector. 191 Mio tons of those emissions are assigned to the production of beef and 193 Mio tons to the production of milk. This is equivalent to 22.2 kg of $CO_{2\text{-eq}}$ per kg of beef and 1.4 kg $CO_{2\text{-eq}}$ per kg of raw milk. In case of beef 8.79 kg (39.6%) are emitted in form of methane, 5.77 kg (26%) as N_2O and 7.61 kg (34.4%) as CO_2, 3.65 kg (16.5%) of CO_2 emissions coming from the use of energy and 3.96 kg (17.9%) from land use and land use change (Scenario II). According to the land use change scenarios (see section 6.3.4) emissions from land use and land use change could, however, range between 2.86 kg (Scenario I) and 9.41 kg (Scenario

III). For milk the shares of the gases are similar, 0.5 kg (36.7%) are emitted as methane, 0.29 kg (21.3%) as N_2O and 0.57 kg (42%) as CO_2, from which 0.24 kg (17.7%) are due to the use of energy and 0.33 kg (24.3%) to land use and land use change (Scenario II). Emissions from land use and land use change can be within the range of 0.26 kg (Scenario I) and 0.64 kg (Scenario III)

Figure 6.1 shows the differences between EU member states for beef. Therefore, the Total of GHG fluxes ranges from 14.2 kg $CO_{2\text{-eq}}$ per kg of beef in Austria to 44.1 kg in Cyprus. However, most countries show values between 20 and 30 kg (see also Table A8.5 in the Annex). On regional level (see Map 6.1) the Total of GHG fluxes ranges from 6.49 kg in the Italian region “Abruzzo” to 51.16 kg in the Finish region “Laensi-Suomi” (mainly due to high emissions from organic soils). On a first view it seems that due to a less efficient production system the new member states are performing slightly worse than the old member states, in terms of per product emissions, and Mediterranean countries emit more than central European or northern countries. However, this is not generally true, as significantly lower emissions are observed only in a few countries, some of them also being new member states. Moreover, the best performing countries are not necessarily characterized by similar production systems. So, the countries with the lowest emissions per kg of beef are as diverse as Austria and the Netherlands. However, while the Netherlands save emissions especially with low methane and N_2O rates indicating an efficient and industrialized production structure, 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. However, both countries are characterized by high meat yields, while e.g. the high emissions in Latvia are in first line due to very low meat yields and, therefore, a less efficient production structure. Moreover, both Latvia and Cyprus show very high emissions from land use change, in case of Cyprus due to high import shares, in case of Latvia due to own expansions of agricultural area supposed to be on the cost of grasslands. Therefore, generally, above average values, if observed in all gas categories, indicate low meat yields. High methane emissions in particular indicate high shares of time animals spend on pastures, or an above average temperature like in Mediterranean countries leading to higher emissions from manure management. N_2O emissions increase with the share of solid systems or manure fallen on pastures. Finally, high CO_2 emissions indicate a strong dependency on feed imports and, in general, feed crops, and a high use of mineral fertilizers for feed production. In total terms (see Figure 6.4) the largest emitters are France with 45 Mio tons, followed by the United Kingdom, Germany, Spain, Italy and Ireland. Differentiating by livestock production systems, as defined in chapter 3, in the BOMILK sector intensive maize and extensive grassland systems produce the least total emissions while free ranging subsistence and climate constrained systems emit more. In the BOMEAT sector intensive maize systems show the lowest and subsidiary systems the highest emissions (see Figure 6.2 and Figure 6.3).

The variability of cow milk emissions among member states is presented in Figure 6.7. The Total of GHG fluxes per kg of milk ranges from 1 kg $CO_{2\text{-eq}}$ per kg of milk in Austria and Ireland to 2.7 kg in Cyprus. Most old member states are in between the range of 1kg and 1.4 kg, while new member states show generally values above 1.5 kg (see Table A8.10 in the Annex). To some degree this difference is driven by lower milk yields in the new member states, as in the case of Bulgaria, Romania, Lithuania and Latvia. However, in contrast to beef production, high milk yields are more related to the consumption of feed concentrates. Therefore, if feed concentrates are imported from overseas higher milk yields are frequently accompanied by higher emissions from land use change, as in the case of the Netherlands, which shows very low methane emissions but overcompensates

this by land use and land use change emissions. The regional variation of total GHG fluxes can be seen from Map 6.2. It shows the same pattern as already observed on member state level. So, except for Spain the regional variation inside member states is limited. The lowest emissions (0.41 kg), again, can be found in the Italian region “Abruzzo”, the highest ones (3.03 kg) in the Greek region “Kriti”. With respect to livestock production systems (see Figure 6.8 and Figure 6.9), the BOMILK sector shows a very equal distribution of total GHG fluxes, except for the Mediterranean intensive system with higher values. Generally intensive systems create less methane and N_2O emissions than extensive ones, but this compensated by higher emissions from land use and land use change. The lowest emissions are created by the extensive grassland system. The BOMEAT sector varies slightly more, indicating a small advantage of the intensive grass and maize systems. The countries with the highest total emissions from cow milk production (see Figure 6.10) are Germany (35 Mio tons), followed by France (29 Mio tons), the United Kingdom (18 Mio tons), Poland (18 Mio tons), the Netherlands (15 Mio tons) and Italy (13 Mio tons). The overwhelming part of the emissions comes from intensive grass and maize systems in the BOMILK sector and intensive grass and maize, intensive maize and complement to ovine systems in the BOMEAT sector (see Figure 6.11 and Figure 6.12).

For the exact emission factors of the different emission sources see Tables A6.1 to 6.10 in the Annex, for total emissions 6.11 to 6.20 respectively. In addition to Greenhouse gas emissions Tables A6.4, A6.9, A6.14 and A6.19 show the respective emission factors and total emissions of NH_3 and NO_X. Therefore average EU-27 NH_3-emissions per kg of beef amount to 74 g of N per kg of beef and 4.4 g N per kg of milk. NO_X emissions amount to 2.3 g N per kg of beef and 0.13 g per kg of milk. Beef emission factors for NH_3 are highest in Latvia (138 g), followed by Lithuania (110 g), Portugal (101 g) and Greece (101 g), and lowest in Finland (44 g). For NO_X the highest values are calculated for Latvia (4 g), the lowest one for the Netherlands (1.2 g). For milk the NH_3 emission factors range from 2.8 g per kg in Netherlands to 7.3 g in Malta, the NO_X emission factors from 0.1 g in Belgium to 0.2 g in Cyprus, Latvia and Malta. Total emissions of the EU-27 are estimated at 637 thousand tons of N from NH_3 and 20 thousand tons of N from NO_X.

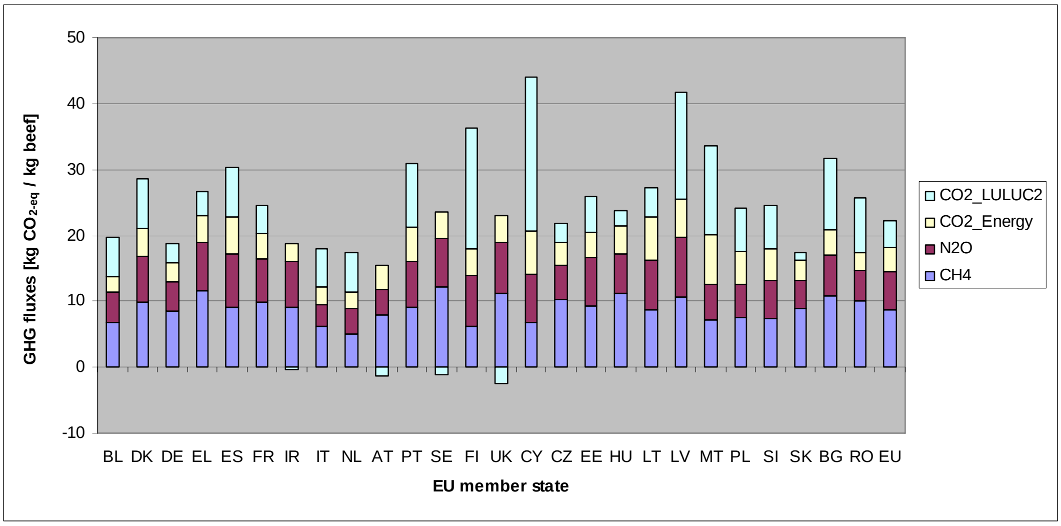


Figure 6.1: Total GHG fluxes of Beef Production in kg CO_{2-eq} per kg Beef by EU member states and Greenhouse Gases

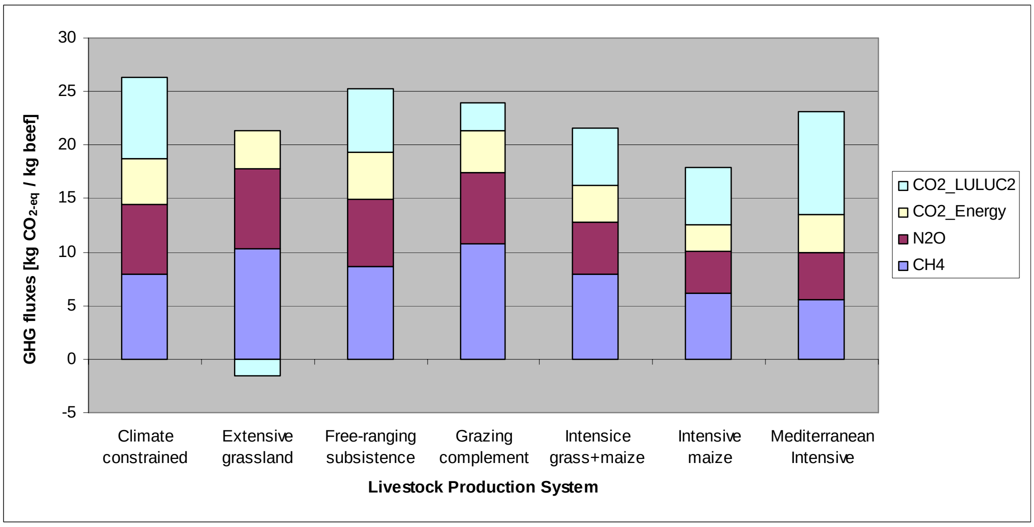


Figure 6.2: Total GHG fluxes of Beef Production in the BOMILK-sector in kg $CO_{2\text{-}eq}$ per kg Beef by livestock production system and Greenhouse Gases

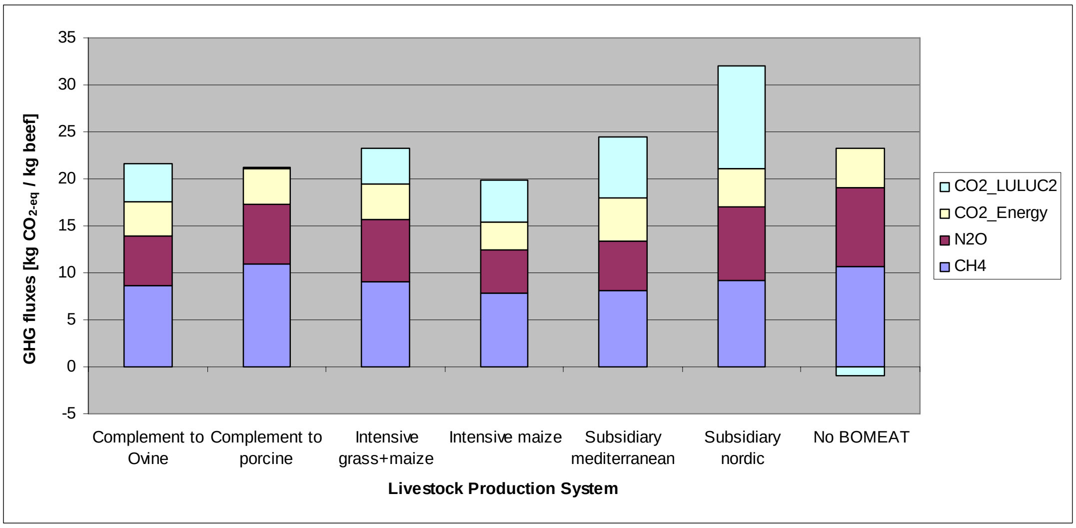


Figure 6.3: Total GHG fluxes of Beef Production in the BOMEAT-sector in kg $CO_{2\text{-}eq}$ per kg Beef by livestock production system and Greenhouse Gases

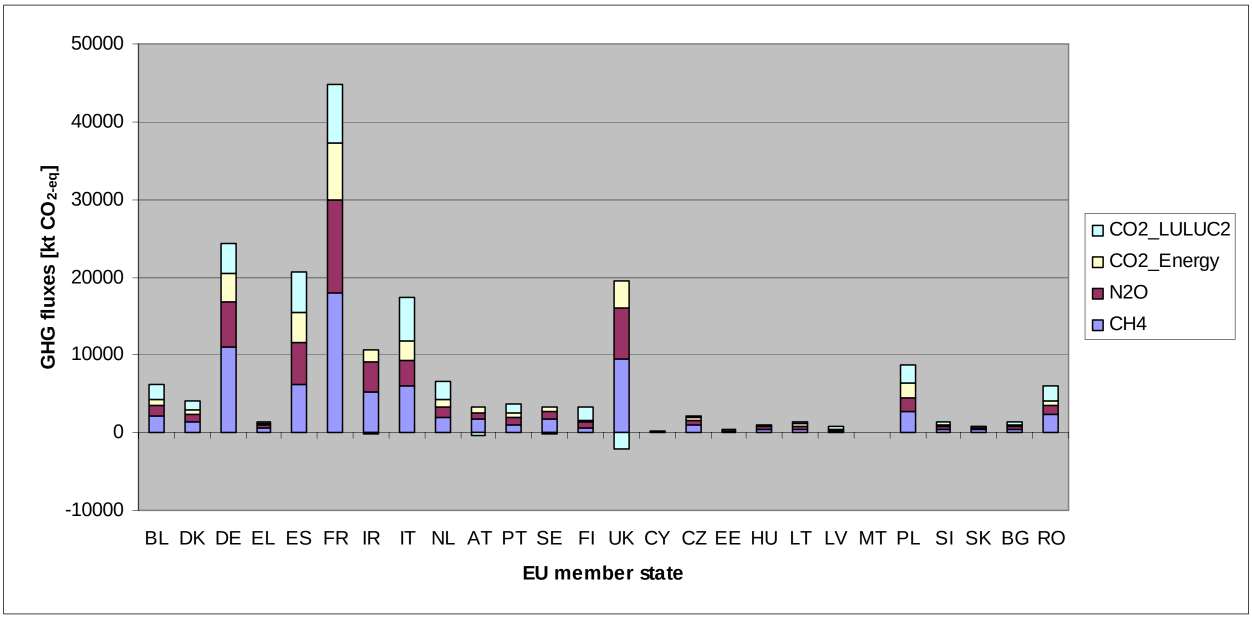


Figure 6.4: Total GHG fluxes of Beef Production in 1000 tons of $CO_{2\text{-}eq}$ by EU member states and Greenhouse Gases

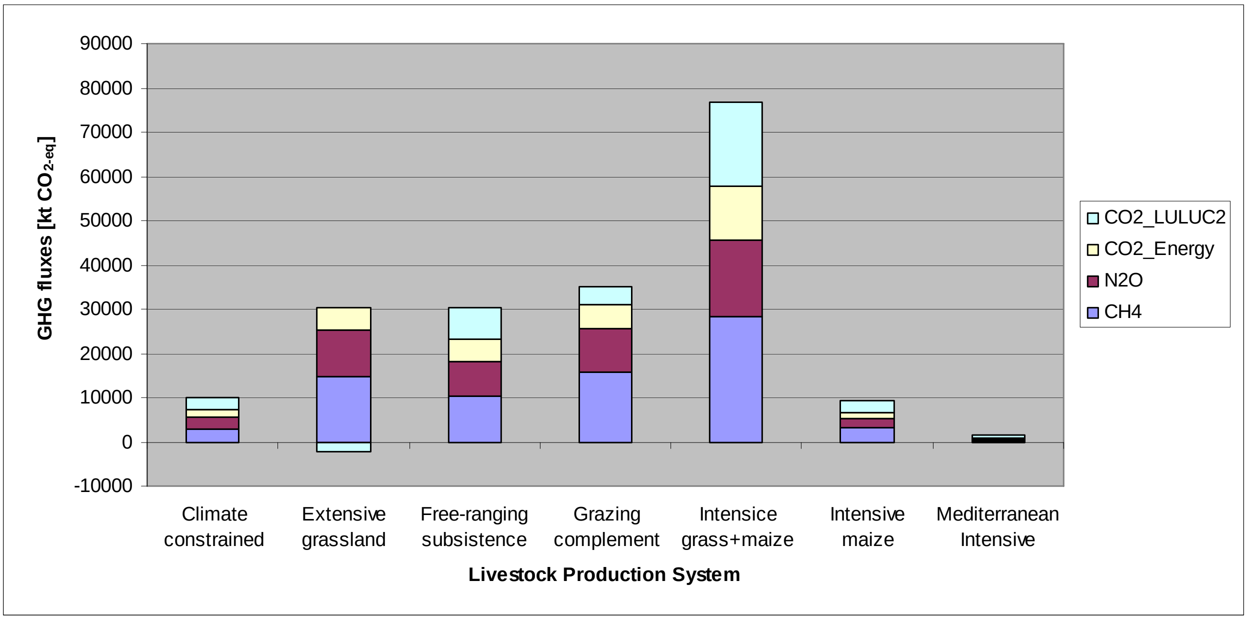


Figure 6.5: Total GHG fluxes of Beef Production in the BOMILK-sector in 1000 tons of $CO_{2\text{-}eq}$ by livestock production system and Greenhouse Gases

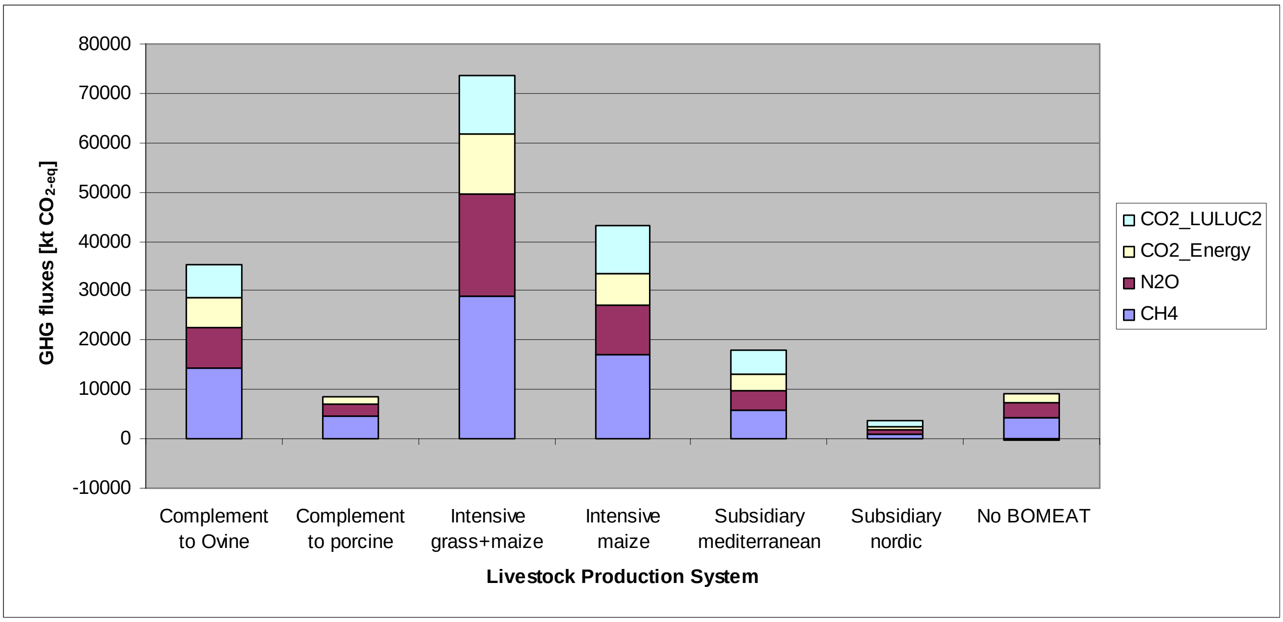


Figure 6.6: Total GHG fluxes of Beef Production in the BOMEAT-sector in 1000 tons of $CO_{2\text{-}eq}$ by livestock production system and Greenhouse Gases

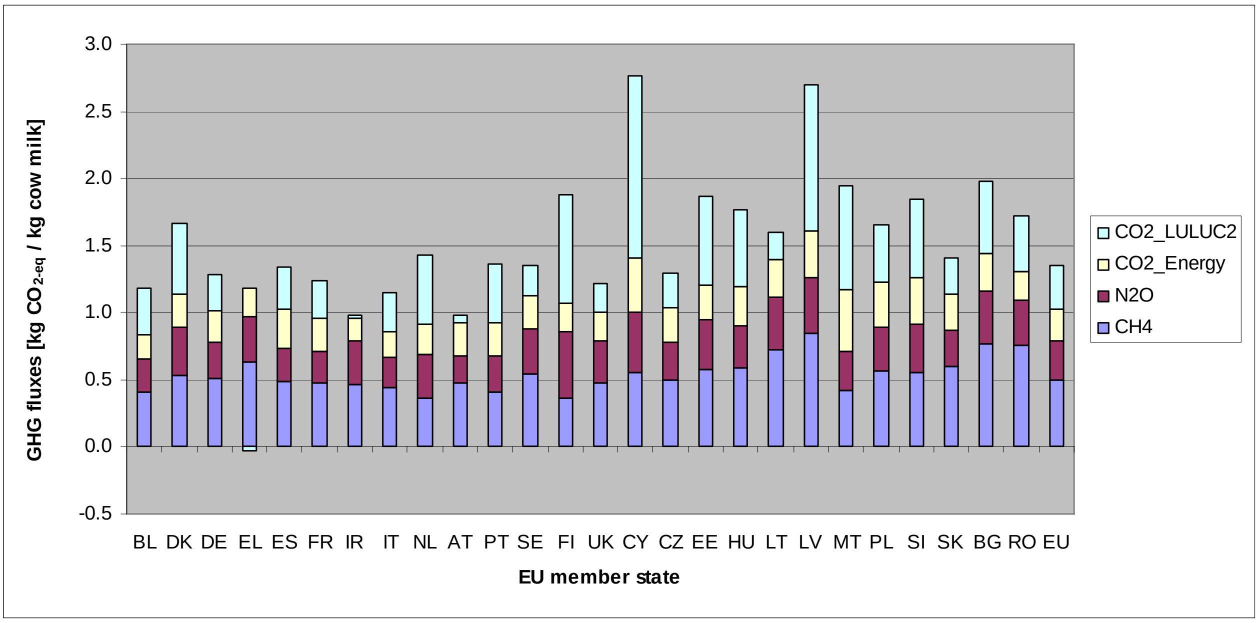


Figure 6.7: Total GHG fluxes of Cow Milk Production in kg $CO_{2\text{-}eq}$ per kg Milk by EU member states and Greenhouse Gases

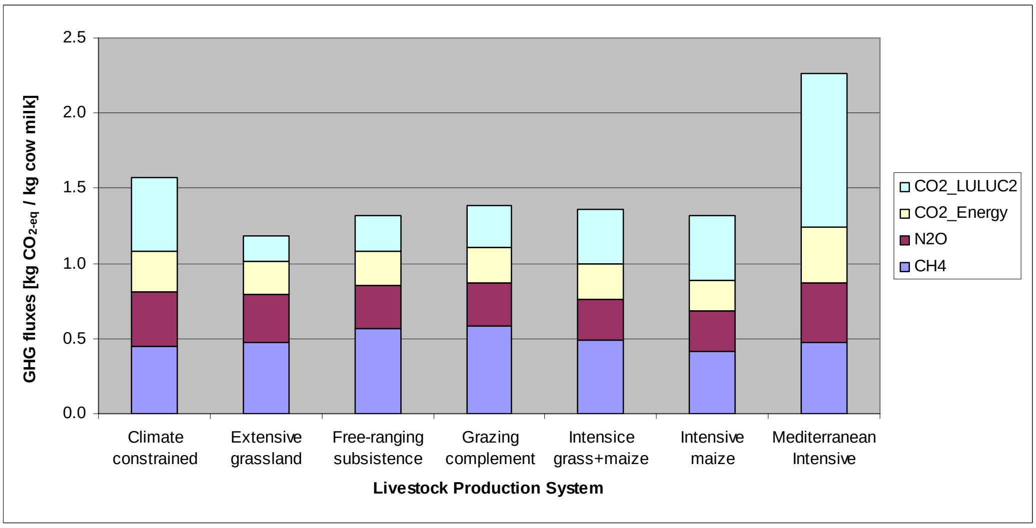


Figure 6.8: Total GHG fluxes of Cow Milk Production in the BOMILK-sector in kg $CO_{2\text{-}eq}$ per kg Milk by livestock production system and Greenhouse Gases

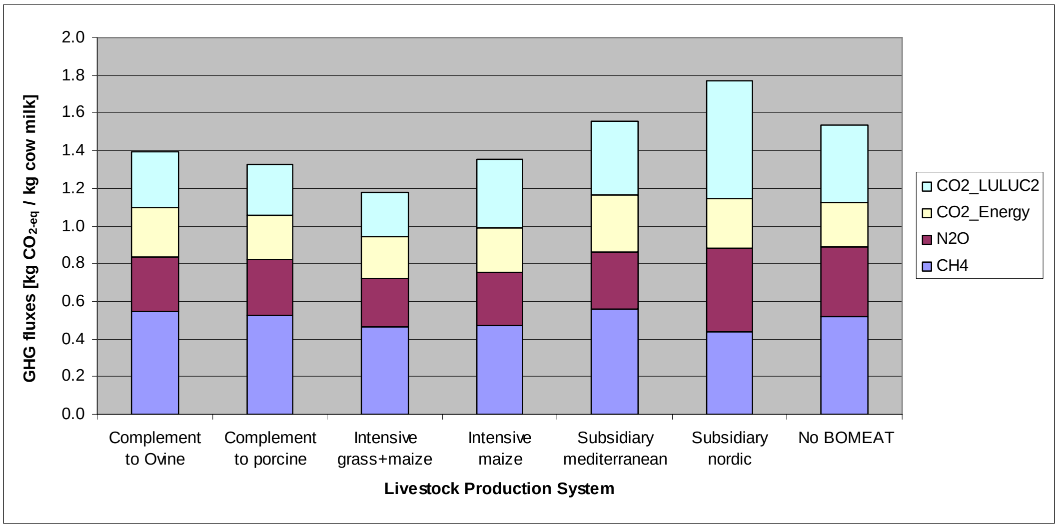


Figure 6.9: Total GHG fluxes of Cow Milk Production in the BOMEAT-sector in kg $CO_{2\text{-}eq}$ per kg Milk by livestock production system and Greenhouse Gases

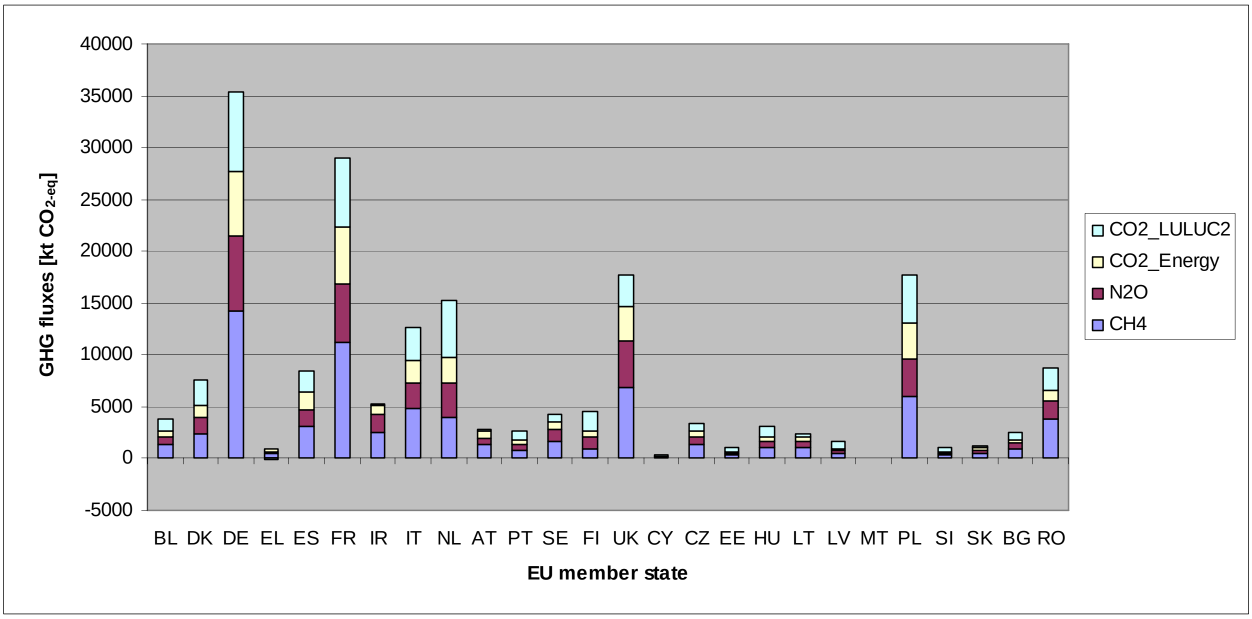


Figure 6.10: Total GHG fluxes of Cow Milk Production in 1000 tons of $CO_{2\text{-}eq}$ by EU member states and Greenhouse Gases

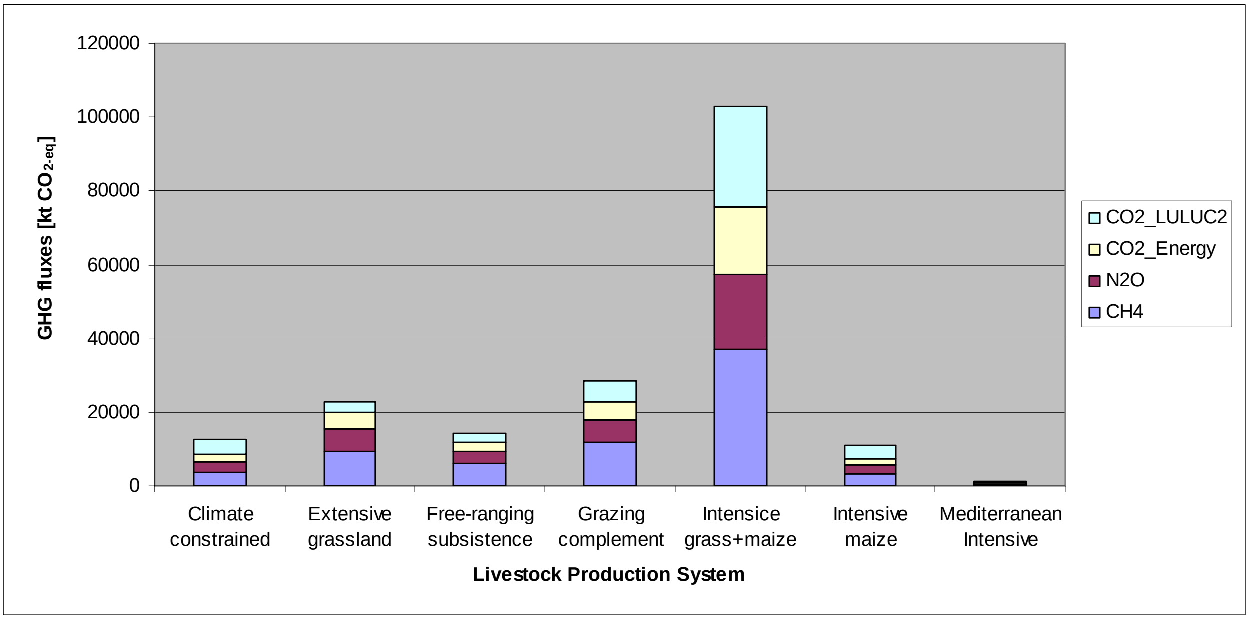


Figure 6.11: Total GHG fluxes of Cow Milk Production in the BOMILK-sector in 1000 tons of $CO_{2\text{-}eq}$ by livestock production system and Greenhouse Gases

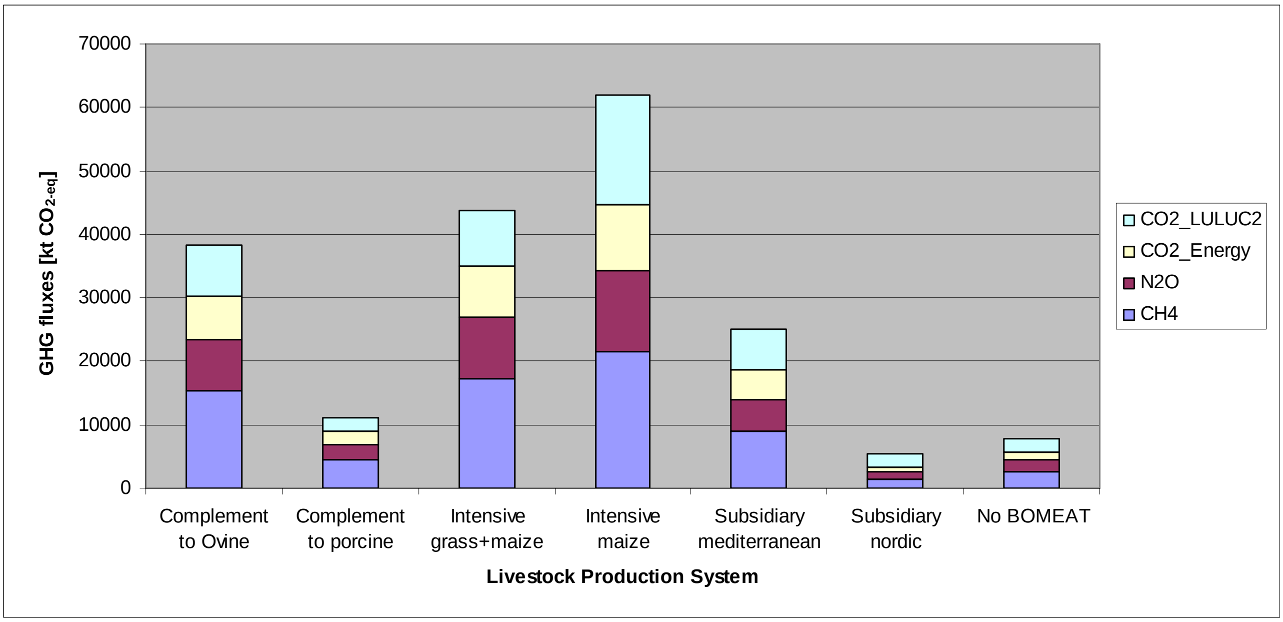
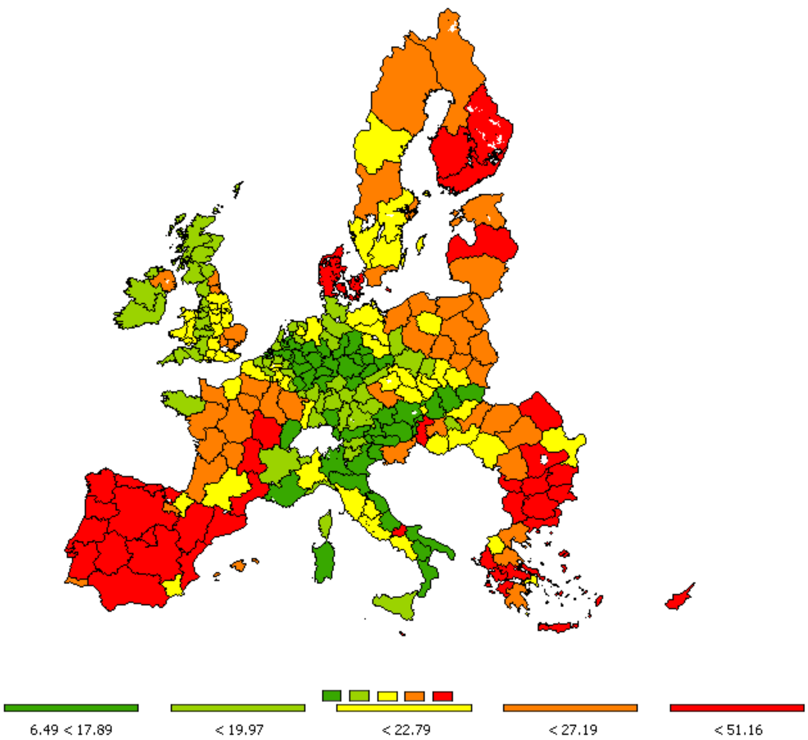
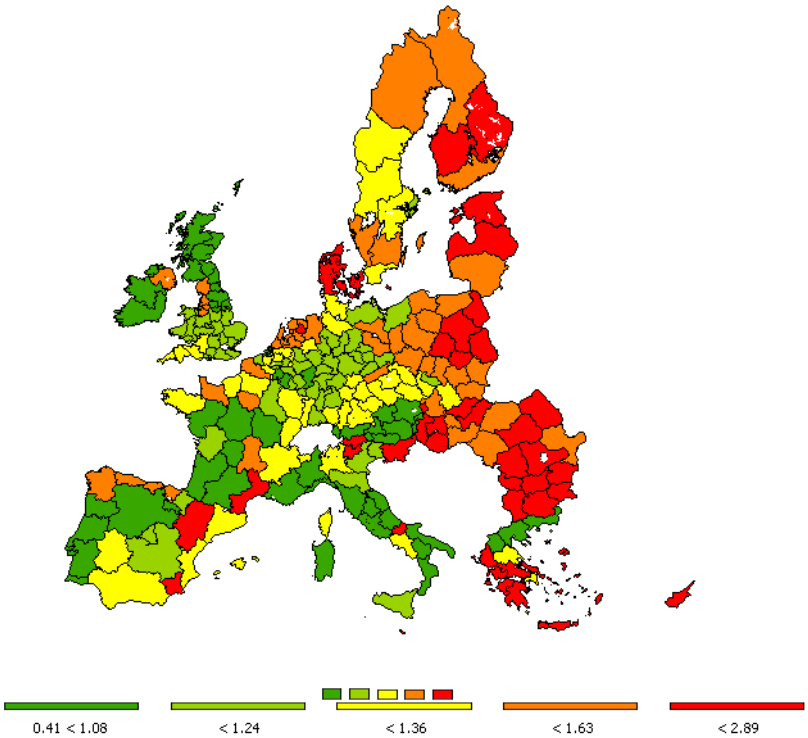


Figure 6.12: Total GHG fluxes of Cow Milk Production in the BOMEAT-sector in 1000 tons of $CO_{2\text{-}eq}$ by livestock production system and Greenhouse Gases



Map 6.1: Total GHG fluxes of Beef Production in kg $CO_{2\text{-}eq}$ per kg Beef by NUTS2 regions



Map 6.2: Total GHG fluxes of Cow Milk Production in kg $CO_{2\text{-}eq}$ per kg Milk by NUTS2 regions

6.3. Pork production

Pork production creates significantly less GHG emissions than beef production, which is mainly due to a more efficient digestion system of pigs and the absence of methane emissions from enteric fermentation. On average EU-27 emits 7.5 kg of $CO_{2\text{-}eq}$ per kg of pork, which is about 34% of the emissions created by the production of beef. In contrast to beef, methane emissions play a less important role (see Figure 6.13), while emissions from energy use and land use and land use change account for a much higher share of total emissions. In fact, only 0.74 kg (10%) of total GHG fluxes come from methane, 1.7 kg (23%) from N_2O, but 4.1 kg (67%) from CO_2, which is further divided into 2 kg (27%) from the use of energy and 3.1 kg (41%) from land use and land use change (Scenario II). However, CO_2 emissions per kg of pork are still around 33% lower than those per kg of beef. Emissions from land use and land use change range between 2.5 kg (Scenario I) and 5.8 kg (Scenario III). Total emissions of pork production in the EU-27 amount to 165 Mio tons of $CO_{2\text{-}eq}$, which is around 86% of emissions from beef production. Among EU member states (see Figure 6.13) the lowest emitting countries (on a per kg basis) are Ireland (4.8 kg) and Greece (5.9 kg), while the highest emission factors can be observed in Latvia (20.3 kg) and Finland (14.5 kg). On regional level emissions per kg of pork range from 4.7 kg $CO_{2\text{-}eq}$ per kg of pork in the Irish region “Southern and Eastern” to 20.3 kg in Latvia, which is not subdivided in NUTS2 regions (see Map 6.3). The variation of emissions is largest for CO_2-emissions, especially for emissions from land use and land use change, since intensive pork production systems apply diets with high shares of feed concentrates frequently imported from overseas. The extraordinarily high emissions in Latvia, Finland and Estonia, however, are due to domestic land use and land use changes. CO_2-emissions from energy use differ especially for heating gas (other fuels) and indirect emissions from buildings

and machinery (see Table A6.28 in the annex) indicating different stable systems, while variations of N_2O emissions are present in all emission source categories. The strong link with NH_3 emission reduction measures (see section 6.2.2), however, entails a need of detailed analysis for explaining numbers for each single case. The exact N_2O-emissions for all emission sources are presented in Table A8.22 in the annex. Finally, lower methane emissions in the new member states are generally due to the lower Tier 1 emission factors for Eastern European countries suggested by the IPCC (see Table 4.3).With respect to total emissions Germany (32 Mio tons), Spain (27 Mio tons), France (14 Mio tons), Italy 12 Mio tons), Denmark (15 Mio tons), the Netherlands (14 Mio tons), Belgium (7 Mio tons) and Poland (13 Mio tons) are the dominant emitters from pork production in EU-27 (see Figure 6.14).

NH_3 and NO_X emission factors are presented in the Table A6.24 and A6.25 of the annex. Therefore NH_3 emissions in kg N per kg pork amount to 28 g in the EU-27 average, NO_X emissions to 0.7 g. This is about 37% of beef emissions for NH_3 and 30% for NO_X. The reason for the big difference is, as in the case of Greenhouse gases, the more efficient digestion system of pigs. Among EU member states Hungary (42 g), Latvia (42 g) and Italy (42 g) show the highest, Finland (15 g), Ireland (19 g) and the Netherlands (19 g) the lowest NH_3-emissions per kg pf pork. For NO_X emissions the highest value is 1 g in Latvia, the lowest 0.5 g in the Netherlands. For EU-27 total emissions from pork production amount to 606 thousand tons of NH_3, and 15 thousand tons of NO_X, all in terms of N. This is around the same dimension as beef emissions for NH_3, but less than 25% of total beef emissions for NO_X. The highest NH_3 emitting countries are Germany (111 thousand tons), Spain (77 thousand tons), Italy (62 thousand tons), France (60 thousand tons), Poland (57 thousand tons) and Denmark (52 thousand tons). For NO_X emissions it is Germany (3.4 thousand tons) and Spain (1.9 thousand tons), while all other countries emit significantly less (see Table A6.30).

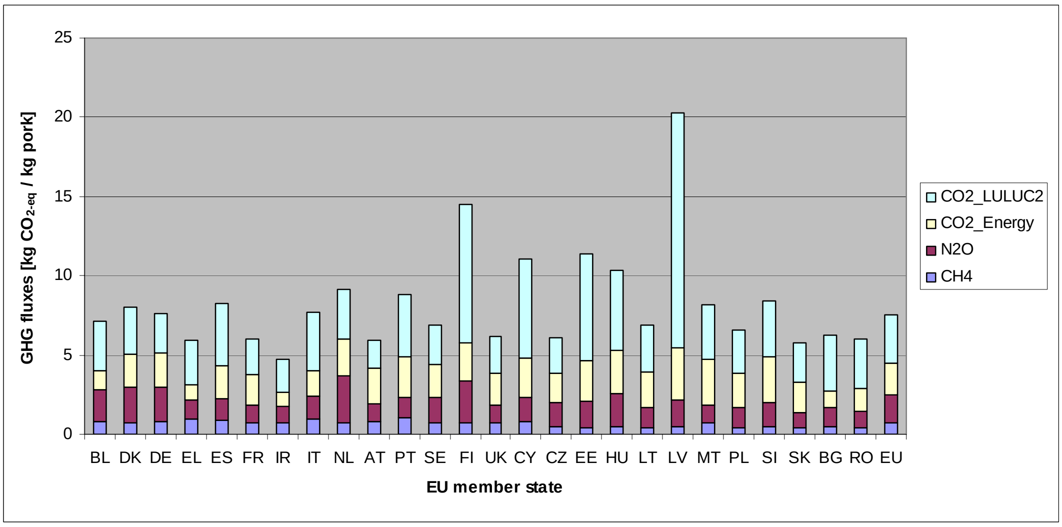


Figure 6.13: Total GHG fluxes of Pork Production in kg $CO_{2\text{-}eq}$ per kg Pork by EU member states and Greenhouse Gases

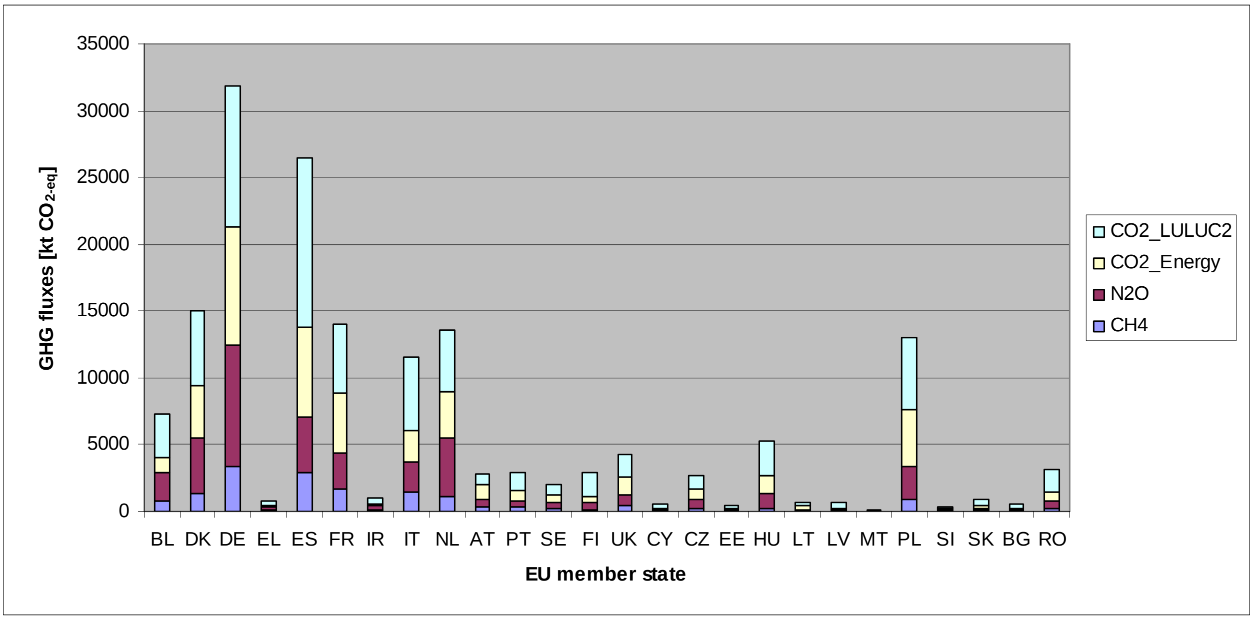
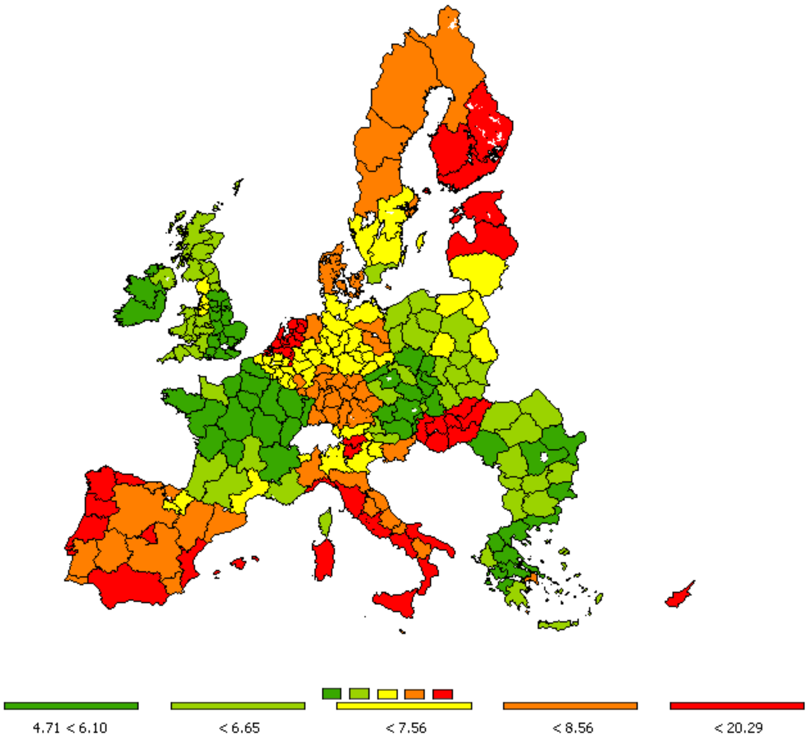


Figure 6.14: Total GHG fluxes of Pork Production in 1000 tons of $CO_{2\text{-}eq}$ by EU member states and Greenhouse Gases



Map 6.3: Total GHG fluxes of Pork Production in kg $CO_{2\text{-}eq}$ per kg Pork by NUTS2 regions

6.4. Sheep and Goat milk and meat production

The production of sheep and goat meat creates total GHG fluxes of 20.3 kg $CO_{2\text{-eq}}$ per kg of meat on EU-27 average, while the estimated emissions of 1 kg of sheep and goat milk amount to 2.9 kg of $CO_{2\text{-eq}}$. The Total of GHG fluxes of meat is composed of 9.2 kg (45%) methane, 4.3 kg (21%) N_2O, 3.2 kg (16%) CO_2-emissions from energy use and 3.7 kg (18%) of CO_2 from land use and land use change (Scenario II), always in $CO_{2\text{-eq}}$, while total GHG fluxes of milk break down into 1.4 kg (48%) of methane, 0.7 kg (23%) of N_2O, 0.4 kg (15%) of CO_2 from energy use and 0.4 kg (14%) of CO_2 from land use and land use change (Scenario II). For meat emissions from land use and land use change are supposed to be within the limits of 2.2 kg (Scenario I) and 11.7 kg (Scenario III), for milk between 0.2 kg (Scenario I) and 1.6 kg (Scenario III). In total sheep and goat meat production of the EU-27 creates GHG fluxes of 24 Mio tons, sheep and goats milk production 12 Mio tons.

The national values for total GHG fluxes per kg of sheep and goat meat range between 7.9 kg in the Czech Republic and 52 kg in Hungary (see Figure 6.15), while for sheep and goat milk the it ranges between 1 kg $CO_{2\text{-eq}}$ per kg of milk in the Czech Republic and 10.7 kg in Hungary (see Figure 6.16). Having a look to the regional level, one can see that emission factors do not vary too much among the regions of a country, which, of course, is related to the fact that in many cases parameters applied are only available on national level (see Map 6.4 and Map 6.5). Total GHG fluxes per kg of meat range from 5.6 kg $CO_{2\text{-eq}}$ in the Austrian region “Tirol” to 67.8 kg in the Finish region region “Laensi-Suomi”. Milk emissions range from 0.7 kg in the Austrian region “Tirol” to 11.6 kg in the Hungarian region “Eszak-Alfoeld”. There is no systematic difference between old and new member states, but apparently, in case of meat, the lowest emitting countries are concentrated in the central part of Europe, while northern and southern countries show higher emissions. In case of milk production higher emission factors are mainly located in the South. The differences, in first line, are due to methane emissions and in some countries, for reasons explained above, to CO_2 emissions from land use and land use change. Since methane emissions are calculated according to a Tier 1 approach (see section 4.2.1), high methane emissions indicate low meat yields, or a warmer climate. For the other gases the same holds, what has been explained in the preceding sections. Total GHG emissions from sheep and goat meat production (see Figure 6.17) is dominated by the United Kingdom (7.8 Mio tons) and Spain (5.7 Mio tons), followed by Greece (2 Mio tons), France (1.9 Mio tons) and Ireland (1.4 Mio tons). In case of sheep and goat milk (see Figure 6.18) there are only a few countries with significant amounts of production: Spain, with a total of GHG fluxes of 3.5 Mio tons, Greece with 2.5 Mio tons, France with 2.1 Mio tons, Italy with 1.8 Mio tons and Romania with 0.9 Mio tons of $CO_{2\text{-eq}}$.

NH_3 and NO_X emission factors and total emissions of sheep and goat meat and milk production are presented in the Tables A6.35, A6.40, A6.45, and A6.50 of the Annex. NH_3 emissions amount to 35.7 g per kg of meat and 5.7 g per kg of milk on EU average. NO_X emissions are estimated at 1.7 g per kg of meat and 0.3 g per kg of milk. Therefore, NH_3 emission factors are around 50% lower than those in beef production, but around 30% higher than those in cow milk production. Similarly, NO_X emissions are 25% lower than those in beef production but substantially higher than in cow milk production. On national level NH_3 emissions per kg of sheep and goat meat range between 9.9 g in the Czech Republic and 110 g in Slovenia, while NO_X emissions vary between 0,6 g in the Czech Republic and 4.8 g in Slovenia. Total emissions from sheep and goat meat production in the EU-27 amount to 43 thousand tons N (NH_3) and 2 thousand tons N (NO_X), while milk emissions sum up to 24 thousand tons and 1.2 thousand tons respectively. Spanish sheep and goat meat

production creates 12.6 thousand tons of N (NH_3) and 430 tons of N (NO_X), the British one 11.6 thousand tons and 600 tons respectively. In case of milk production Spain emits 8.8 thousand tons of N (NH_3) and 300 tons N (NO_X).

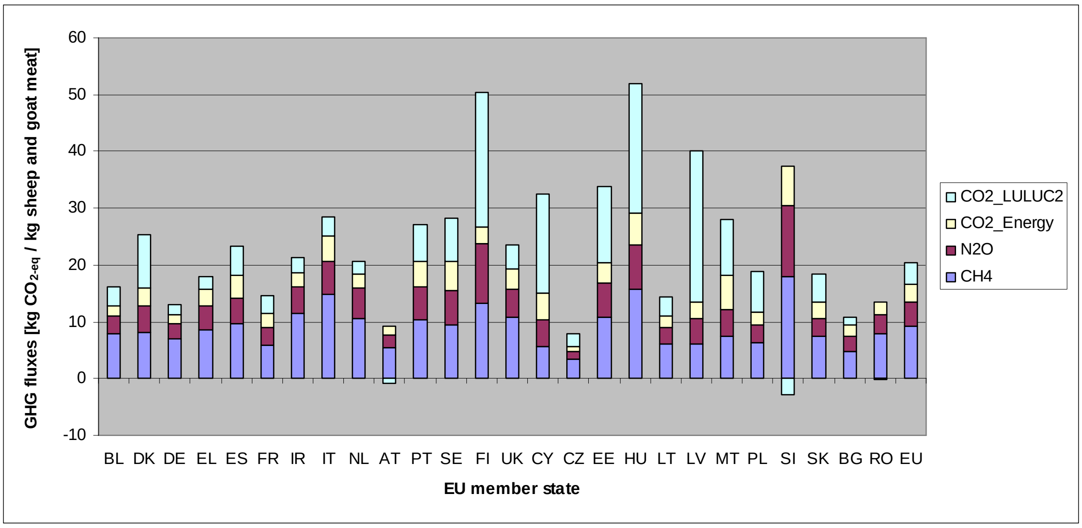


Figure 6.15: Total GHG fluxes of Sheep and Goat Meat Production in kg $CO_{2\text{-}eq}$ per kg Meat by EU member states and Greenhouse Gases

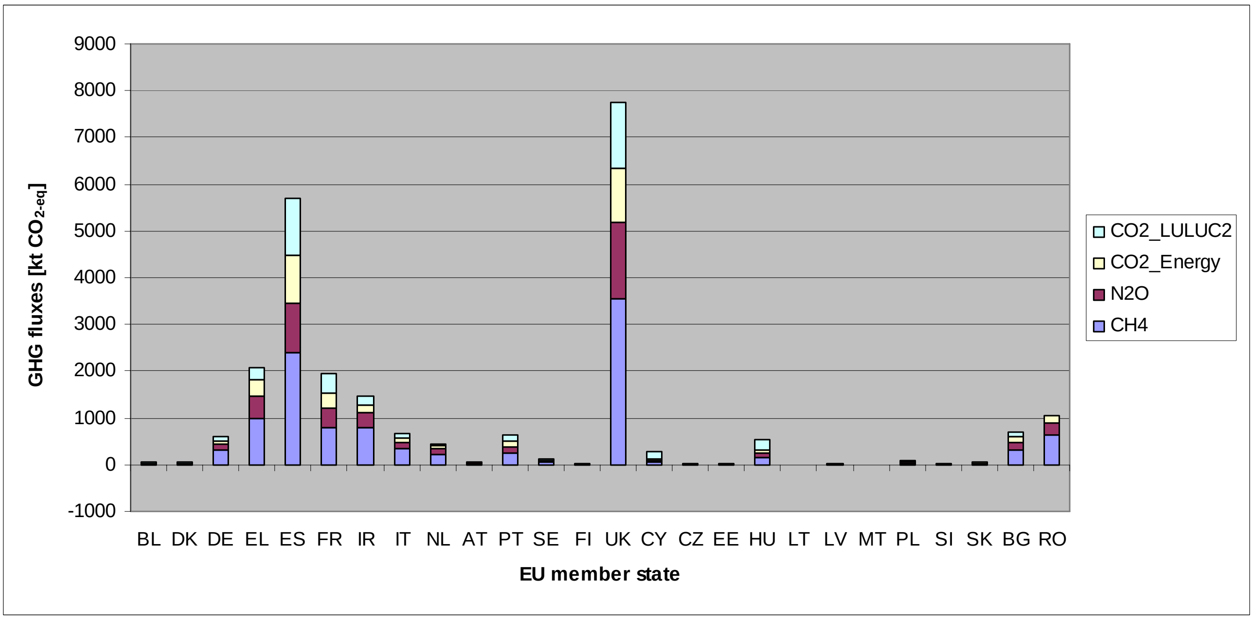


Figure 6.16: Total GHG fluxes of Sheep and Goat Meat Production in 1000 tons of $CO_{2\text{-}eq}$ by EU member states and Greenhouse Gases

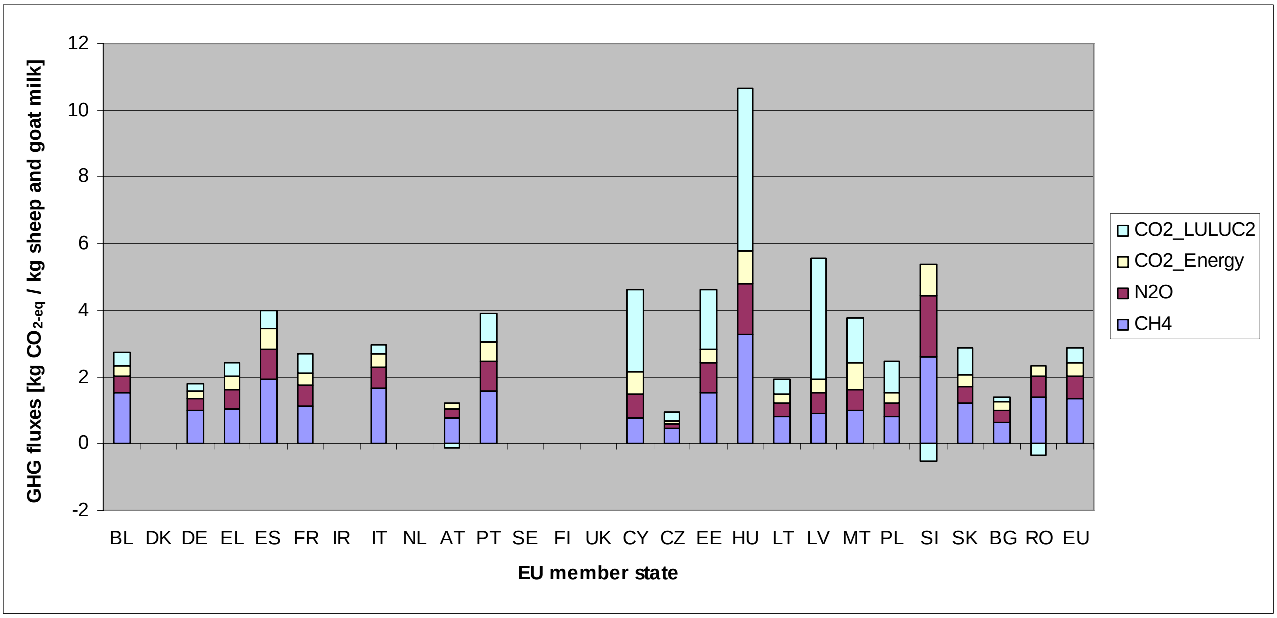


Figure 6.17: Total GHG fluxes of Sheep and Goat Milk Production in kg $CO_{2\text{-}eq}$ per kg Milk by EU member states and Greenhouse Gases

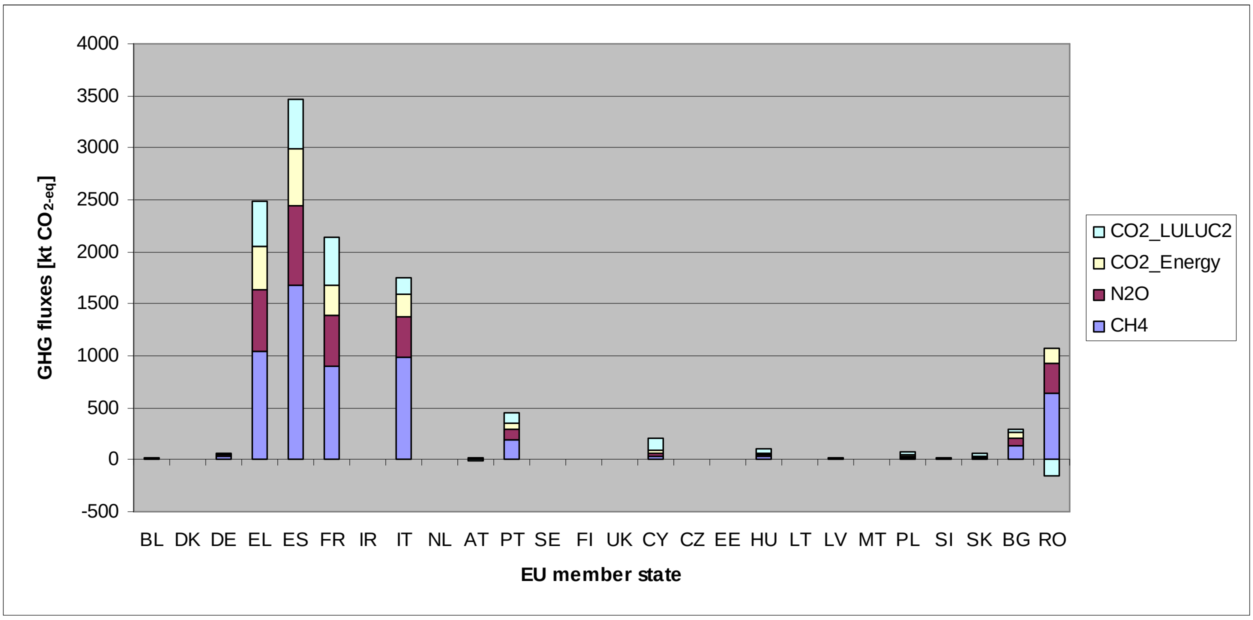
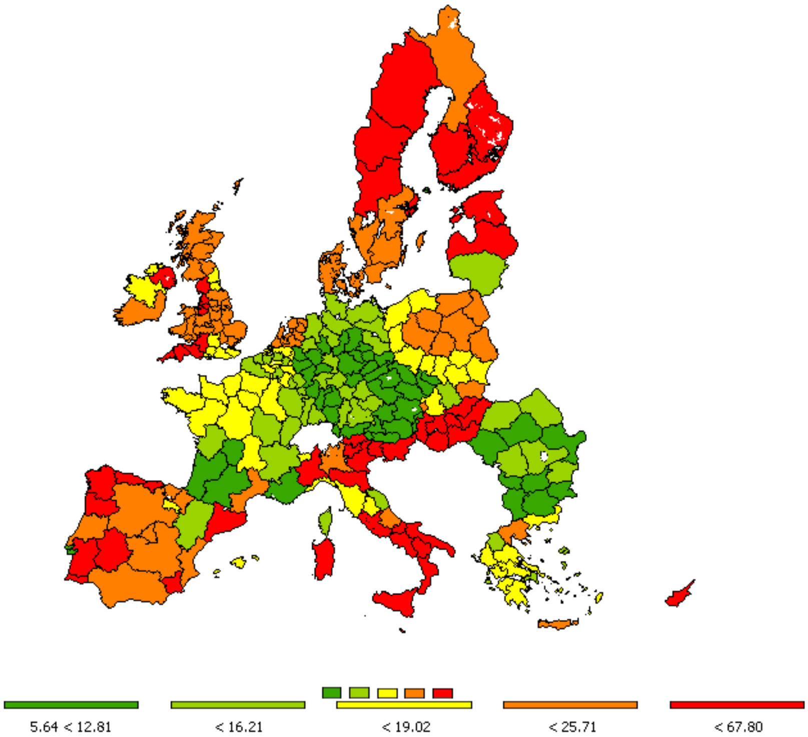
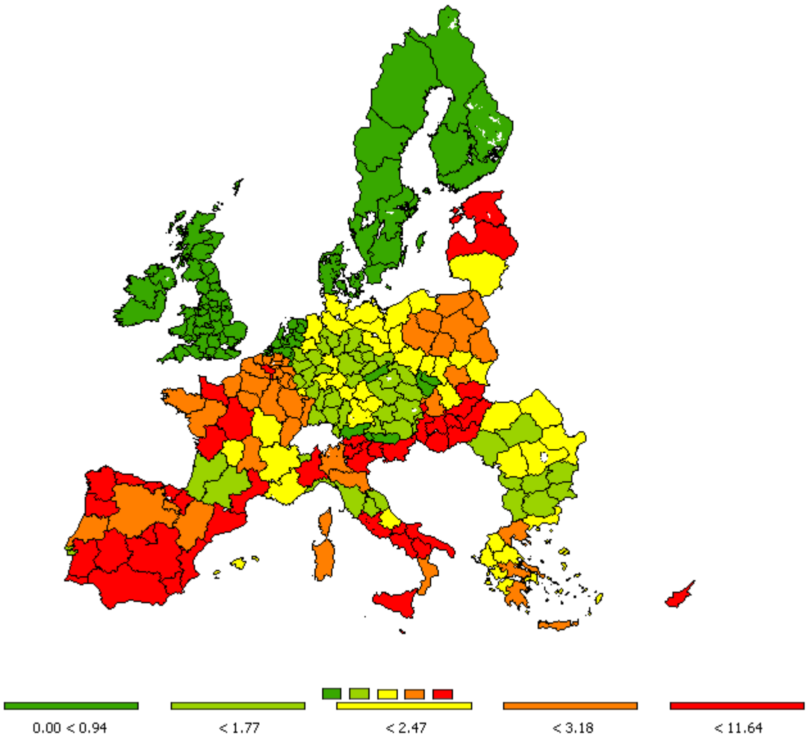


Figure 6.18: Total GHG fluxes of Sheep and Goat Milk Production in 1000 tons of $CO_{2\text{-}eq}$ by EU member states and Greenhouse Gases



Map 6.4: Total GHG fluxes of Sheep and Goat Meat Production in kg CO_{2-eq} per kg Meat by NUTS2 regions



Map 6.5: Total GHG fluxes of Sheep and Goat Milk Production in kg CO_{2-eq} per kg Milk by NUTS2 regions

6.5. Poultry meat and eggs production

According to CAPRI calculations, the EU-27 average of total GHG fluxes per kg of poultry meat is 4.9 kg of $CO_{2\text{-eq}}$, which corresponds to 22% of emissions created per kg of beef and 65% of emissions created per kg of pork. The 4.9 kg are composed of 0.04 kg (1%) of methane, 1.1 kg (21%) of N_2O, 1.4 kg (28%) of CO_2 from energy use and 2.4 kg (50%) CO_2 from land use and land use change (Scenario II). Emissions from land use and land use change are supposed to range from 2.1 kg (Scenario I) to 4.2 (Scenario III). Therefore, the lower GHG fluxes compared to pork production is due to lower emissions in all gases. Lower emissions can be explained by a better feed to output relation, different loss factors and in case of energy related emissions lower energy requirements for stables (see Table A6.53 in the Annex). Total GHG fluxes from poultry meat production in EU-27 amount to 54 Mio tons of $CO_{2\text{-eq}}$, which is 28% of the emissions created by beef production and 33% of the emissions created by pork production. The production of eggs leads to the emission of 2.9 kg of $CO_{2\text{-eq}}$ per kg of eggs on EU average, which breaks down into 0.03 kg (1.1%) of methane, 0.77 kg (27%) of N_2O, 0.75 kg (26%) of CO_2 from energy use and 1.33 kg (46%) of CO_2 from land use and land use change (Scenario II). Emissions from land use and land use change range between the limits of 1.26 kg (Scenario I) and 1.69 kg (Scenario III). Total emissions from EU egg production amount to 20.6 Mio tons, which is 38% of emissions from poultry meat production.

On country level poultry meat emissions range between 3.3 kg $CO_{2\text{-eq}}$ per kg of poultry in Ireland and 17.8 kg in Latvia (see Figure 6.19). Variations are mainly due to CO_2 emissions from lad use and land use change, particularly in the countries with substantial emissions from domestic land use change, like Latvia and Estonia. The high N_2O emissions of the Netherlands are related to a high application rate of NH_3-reduction measures, which are supposed to increase N_2O emissions in return (see Table 4.8 and

Table 4.13). In contrast, in Cyprus, Malta and Latvia they are mainly related to feed production (see Table A6.52 in the annex). Moreover, some differences can be explained by diverging IPCC default emission factors between old and new member states applied in the model (see section 6.2.2) CO_2 emissions from energy use differ particularly by stable types and in relation to feed production (see Table A8.53 in the Annex). On regional level the lowest emissions can be found in the Irish region “Southern and Eastern” (3.2 kg), while there are no regions with higher emissions than Latvia (see Map 6.6). The Total of GHG fluxes from the production of eggs ranges from 2 kg $CO_{2\text{-eq}}$ per kg of eggs in Austria to 8.7 kg in Cyprus (see Figure 6.21) on national level. On regional level (see Map 6.7) the lowest GHG fluxes from egg production are estimated for the Austrian region “Oberoesterreich” (1.8 kg). The member states with the highest total GHG emissions from poultry meat production (see Figure 6.20) are France (8.7 Mio tons), the United Kingdom (7.1 Mio tons), Spain (8.1 Mio tons), Germany (4.9 Mo tons), Italy (4.7 Mio tons), the Netherlands (3.2 Mio tons), Poland (4.6 Mio tons), Hungary (2.3 Mio tons) and Portugal (1.7 Mio tons). Similarly, emissions from egg production (see Figure 6.22) are dominated by Spain (2.2 Mio tons), France (1.6 Mio tons), the United Kingdom (2.2 Mio tons), Italy (1.7 Mio tons), Poland (1.4 Mio tons), Germany (1.8 Mio tons) and the Netherlands (2 Mio tons).

Finally, NH_3 and NO_X emissions are presented in the Tables A6.54, A6.59, A6.64 and A6.69 in the annex. Average NH_3 emissions per kg of poultry meat are estimated at a level of 20 g, average NO_X emissions at 0.5g. The values per kg of eggs are 12 g and 0.3 g respectively. Among member states the emissions from poultry meat range from 8 g $N(NH_3)$ in Belgium and 0.4 g $N(NO_X)$ in Austria

and the Netherlands to 42 g N(NH_3) and 1 g N(NO_X) in Latvia. Similarly, for the production of eggs Belgium and the Netherlands show the lowest emissions with 6 g N(NH_3) and 0.2 g N(NO_X) per kg of eggs, while Cyprus is supposed to create the highest emissions with 23 g N(NH_3) and 0.7 g N(NO_X). Total NH_3 emissions from EU poultry meat production amount to 217 thousand tons of N, while total NO_X emissions sum up to 5.5 thousand tons of N. For EU egg production the respective total emissions are 88 thousand tons of N(NH_3) and 2.2 thousand tons of N(NO_X).

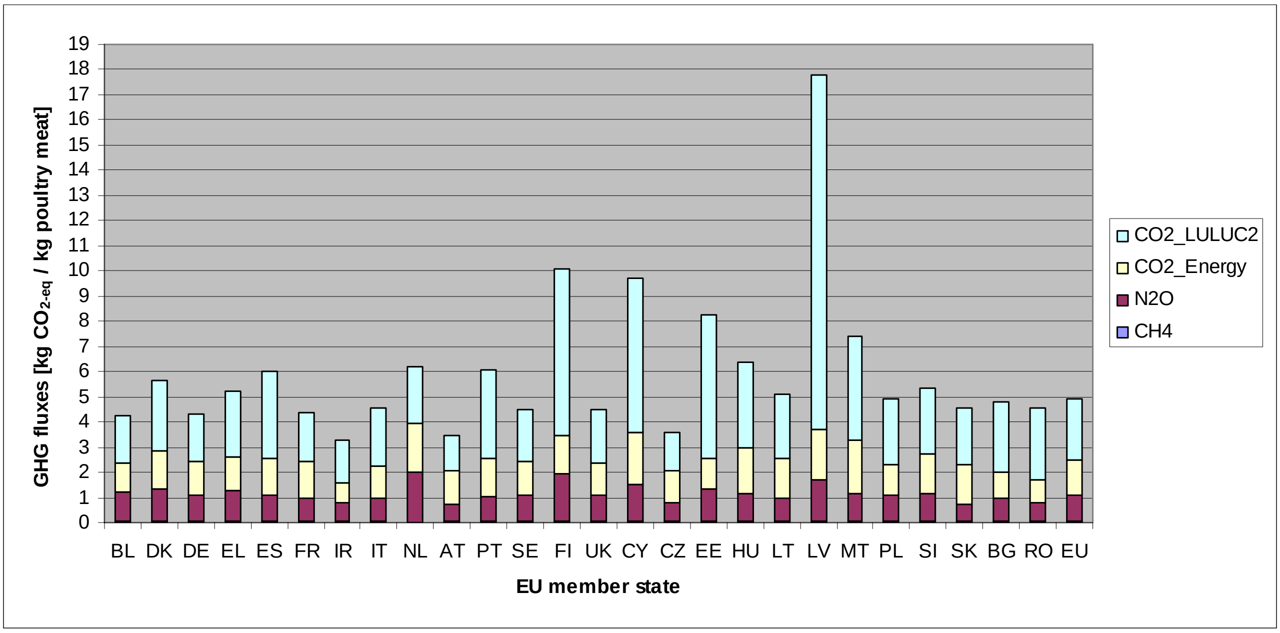


Figure 6.19: Total GHG fluxes of Poultry Meat Production in kg $CO_{2\text{-}eq}$ per kg Meat by EU member states and Greenhouse Gases

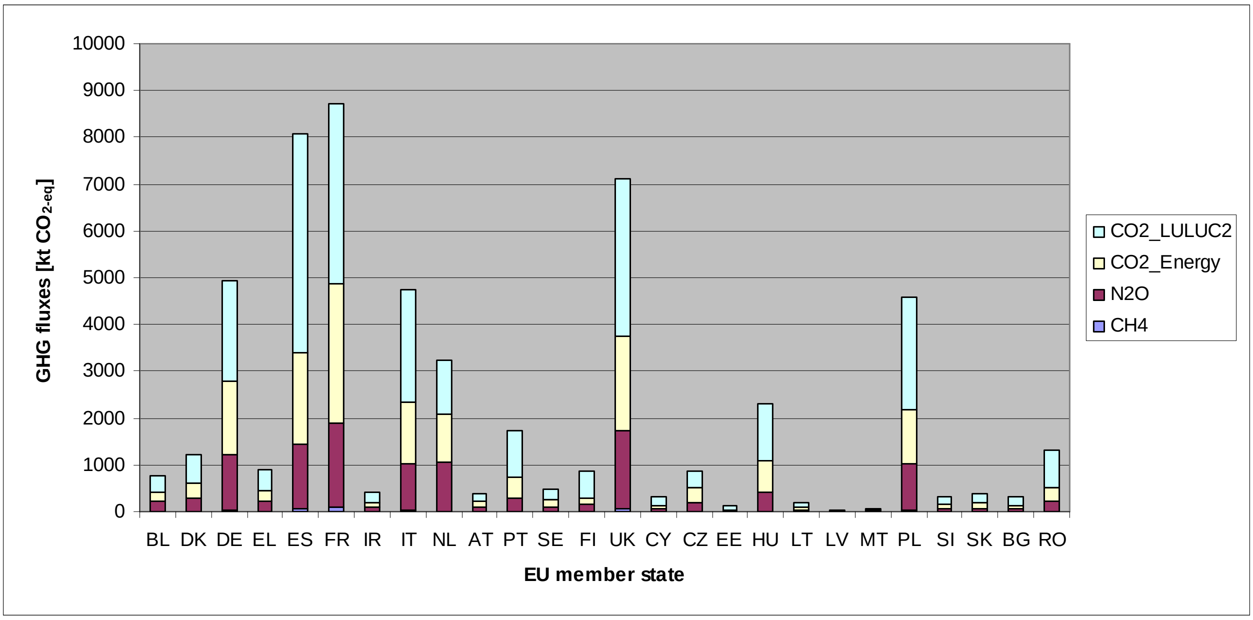


Figure 6.20: Total GHG fluxes of Poultry Meat Production in 1000 tons of $CO_{2\text{-}eq}$ by EU member states and Greenhouse Gases

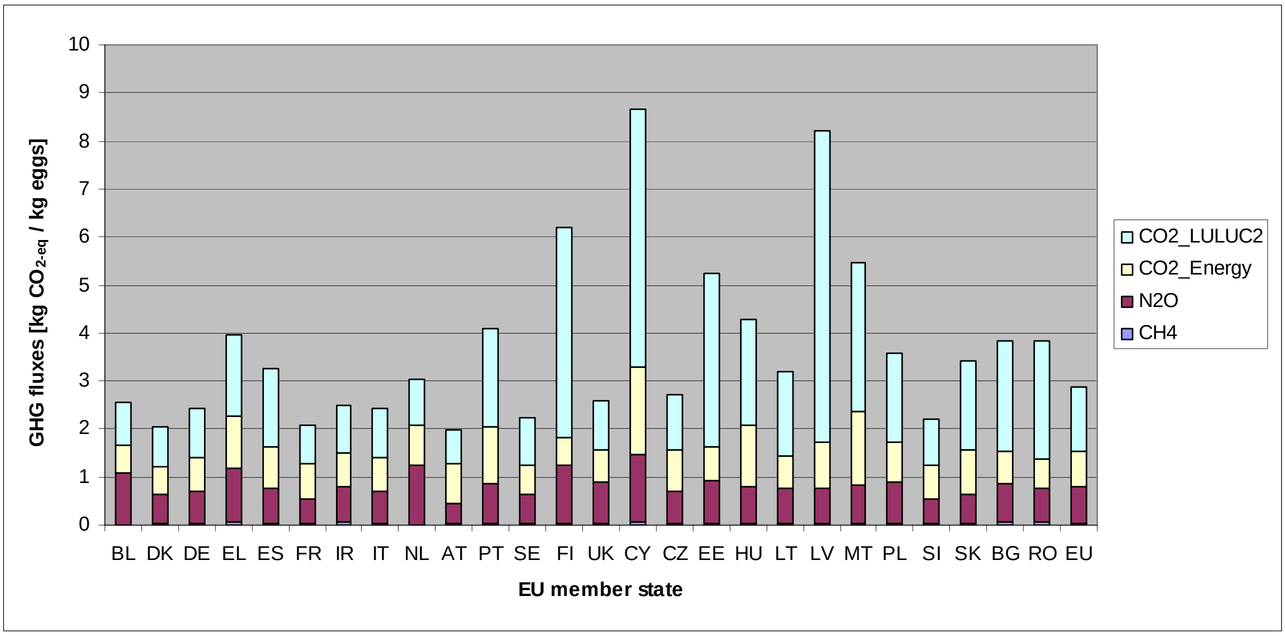


Figure 6.21: Total GHG fluxes of Egg Production in kg $CO_{2\text{-}eq}$ per kg Eggs by EU member states and Greenhouse Gases

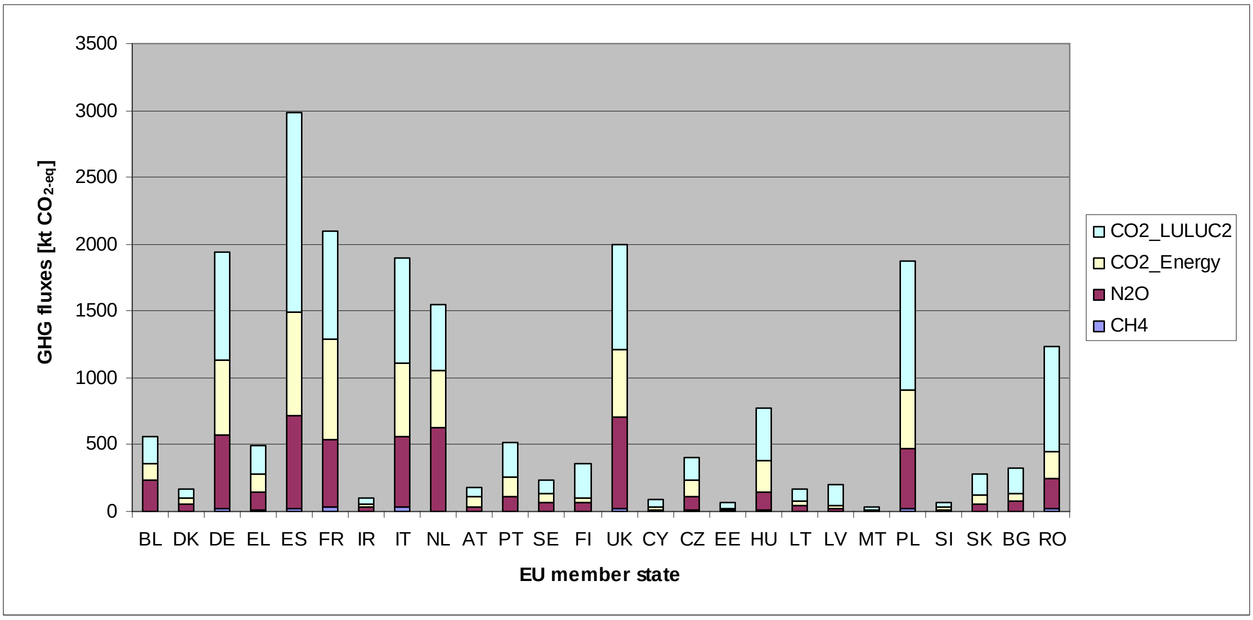
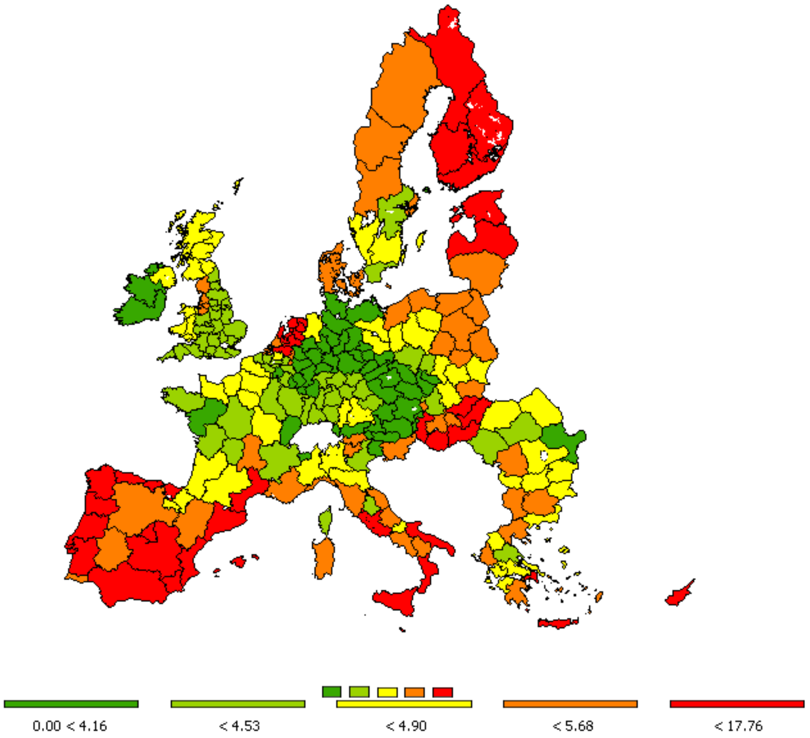
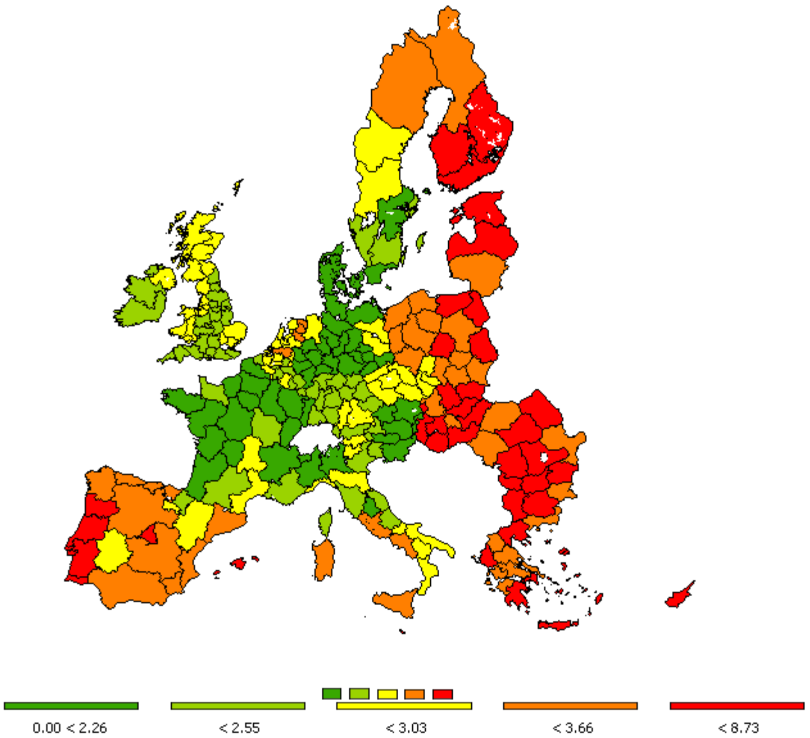


Figure 6.22: Total GHG fluxes of Egg Production in 1000 tons of $CO_{2\text{-}eq}$ by EU member states and Greenhouse Gases



Map 6.6: Total GHG fluxes of Poultry Meat Production in kg CO_{2-eq} per kg Meat by NUTS2 regions



Map 6.7: Total GHG fluxes of Egg Production in kg CO_{2-eq} per kg Eggs by NUTS2 regions

6.6. The role of EU livestock production for greenhouse gas emissions

The Figure 6.23 and Figure 6.24 compare the Totals of GHG fluxes per kg of meat or milk for different meat and milk categories, always on EU average level. As already mentioned above, emissions from ruminant meat production are very similar whether produced by cattle or sheep and goats. Even the shares of the gases to the Total do not differ tremendously. In contrast, the production of pork, due to a more efficient digestion process, creates only around 34% of ruminant emissions, and poultry meat production only 22%. In absolute terms the emission saving is highest for methane, thanks to absent emissions from enteric fermentation, and N_2O emissions, while the difference is smaller for CO_2 emissions. Nevertheless both pork and poultry meat production creates less emissions in all four gas aggregates in absolute terms.

In case of milk production cow milk seems to be less emission intensive than sheep and goat milk production. While cow milk production creates total GHG fluxes of 1.4 kg $CO_{2\text{-eq}}$ per kg of milk, sheep and goat milk accounts for almost 2.9 kg on average. However, one has to keep in mind that the data quality in general is less reliable for sheep and goat production than for dairy and cattle production, which is important for the assignment of emissions to milk and meat.

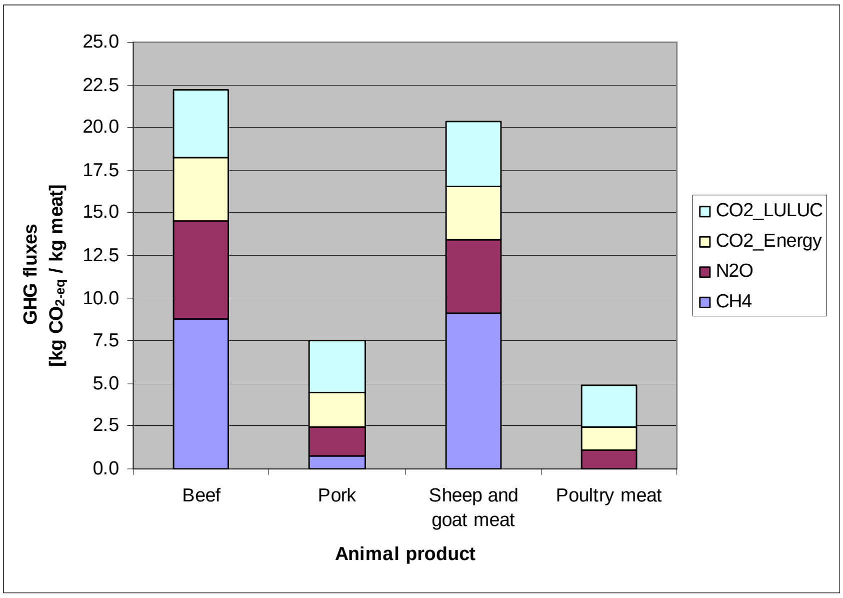


Figure 6.23: Comparison of total GHG fluxes of different meat categories in kg of $CO_{2\text{-eq}}$ per kg of meat

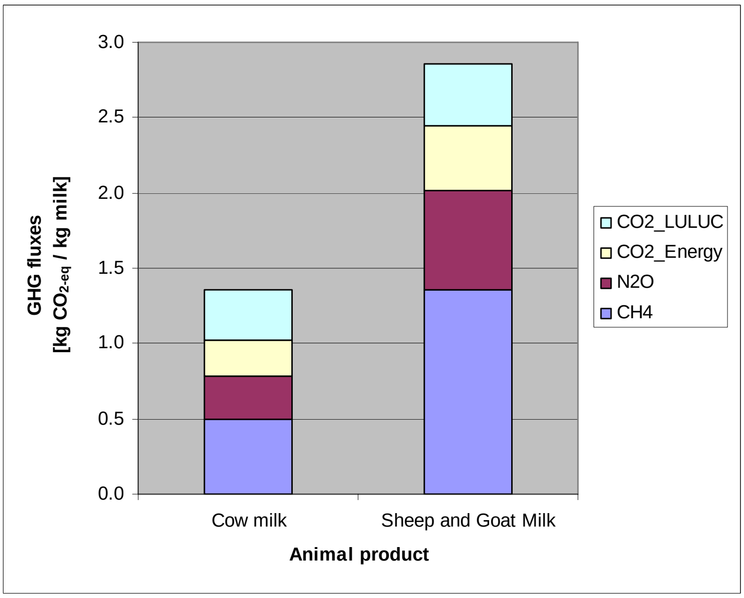


Figure 6.24: Comparison of total GHG fluxes of different milk categories in kg of CO_{2-eq} per kg of milk

With respect to GHG fluxes of total livestock production, beef, cow milk and pork production are the dominant emission sources (see Figure 6.25) in the European Union. Emissions from beef production amount to 191 Mio tons of CO_{2-eq} (29%), from cow milk production to 193 Mio tons (29%) and from pork production to 165 Mio tons (25%), 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, 136 Mio tons (21%) in the energy sector, 11 Mio tons (2%) in the industrial sector and 191 Mio tons (29%) are caused by land use and land use change (Scenario II), mainly in Non-European countries. 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). 181 Mio tons (27%) are emitted as 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).

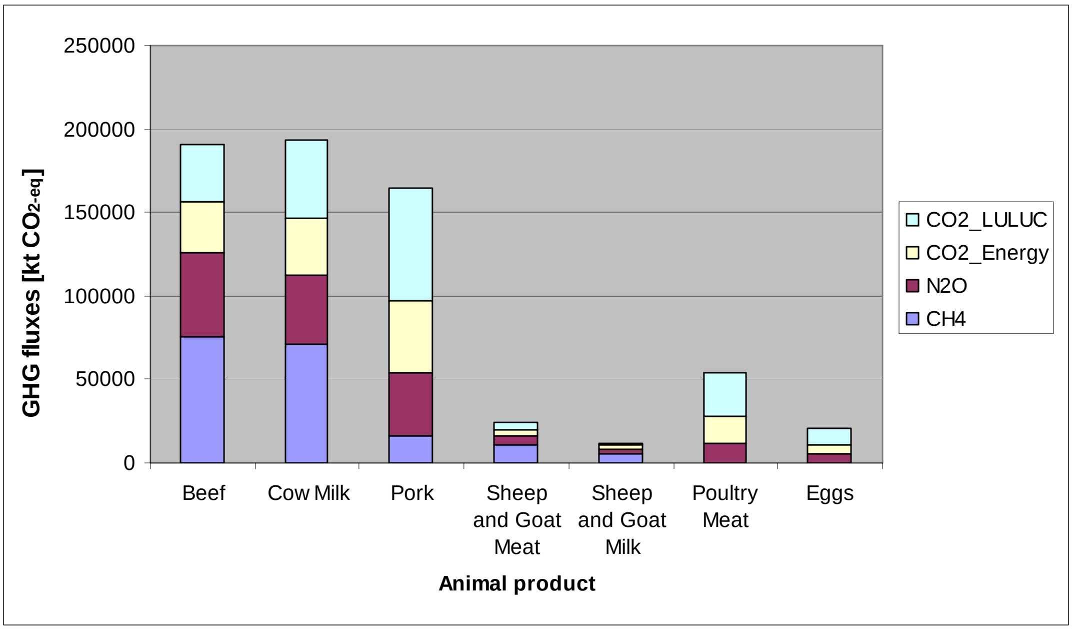


Figure 6.25: Total GHG fluxes of agricultural products in the EU in 1000 tons of $CO_{2\text{-}eq}$

Figure 6.26 relates emissions from livestock production (results of the life cycle assessment) to the emissions from the total agricultural sector (results of the activity based calculation of emissions from the IPCC agriculture sector presented in Chapter 5). The blue bars represent the shares of the emissions from the agricultural sector, the green bars the energy sector, the yellow bars the industry sector and the orange bars the LULUC emissions. Therefore, on EU average livestock emissions from the agricultural sector (basically methane and N_2O) account for 85% of the emissions created by the sector. This share ranges from 63% in Finland to 112% in Cyprus. However, it should be kept in mind that the numbers are not directly comparable, since the LCA considers also emissions from imported feed, which is not the case in the activity based calculation. Adding also emissions from energy use, industries and LULUC (Scenario II) livestock production creates 175% of the emissions estimated for the total agricultural sector if calculated on an activity based approach for agricultural emissions defined by IPCC.

For a comparison of EU livestock emissions from the LCA to the National Inventories it is convenient to first compare Inventories to the activity based emissions in CAPRI. If we sum up all emission sources presented in Chapter 5, both for CAPRI and the National Inventories, and relate those numbers we see that CAPRI generally estimates lower total emissions than the member states (see Figure 6.27). 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 National Inventories.

As a consequence, comparing the LCA results to the results of the National Inventories (see Figure 6.28) the shares are slightly smaller than those presented in Figure 6.26. So, on EU average livestock emissions from the agricultural sector, according to the LCA, are equivalent to 67% of total emissions from the agricultural sector, as reported by the member states. The share ranges from 48% in Hungary to 120% in Denmark. Adding emissions from energy use, industries and

LULUC (Scenario II), on EU average livestock production would amount to 137% of agricultural emissions according to National Inventories, ranging from 91% in Greece to 313% in Malta. Relating emissions from the use of energy in livestock production (LCA results) to total emissions from the energy sector according to National Inventories (see Figure 6.29) shows an average value of 3.3% in the EU-27. The highest share of the livestock sector in total energy emissions can be found in Denmark (11.2%), the lowest one in Greece (1.6%). Doing the same for the emissions from industries indicates an average share of mineral fertilizer production for livestock feeds of 2.6 percent in total industrial sector emissions, ranging from 0.3% in Romania and Slovakia to 18.6% in Ireland (see Figure 6.30).

Finally, Figure 6.31 relates the total GHG fluxes of the livestock sector according to LCA to the total GHG fluxes reported by the member states (National Inventories). The blue bars represent the emissions from the agricultural and the energy sector, the green bars the emissions from land use and land use change (Scenario II), which are mainly related to feed imports from Non-European countries and, therefore, not easily comparable with inventory data. On EU average the livestock sector (land use change excluded) accounts for 9.1% of total emissions, ranging from 4.8% in the Czech Republic to 26.8% in Ireland and Denmark. Considering LULUC, the share increases to 12.8% on EU level, ranging from 6.5% in the Czech Republic to 41.2% in Denmark.

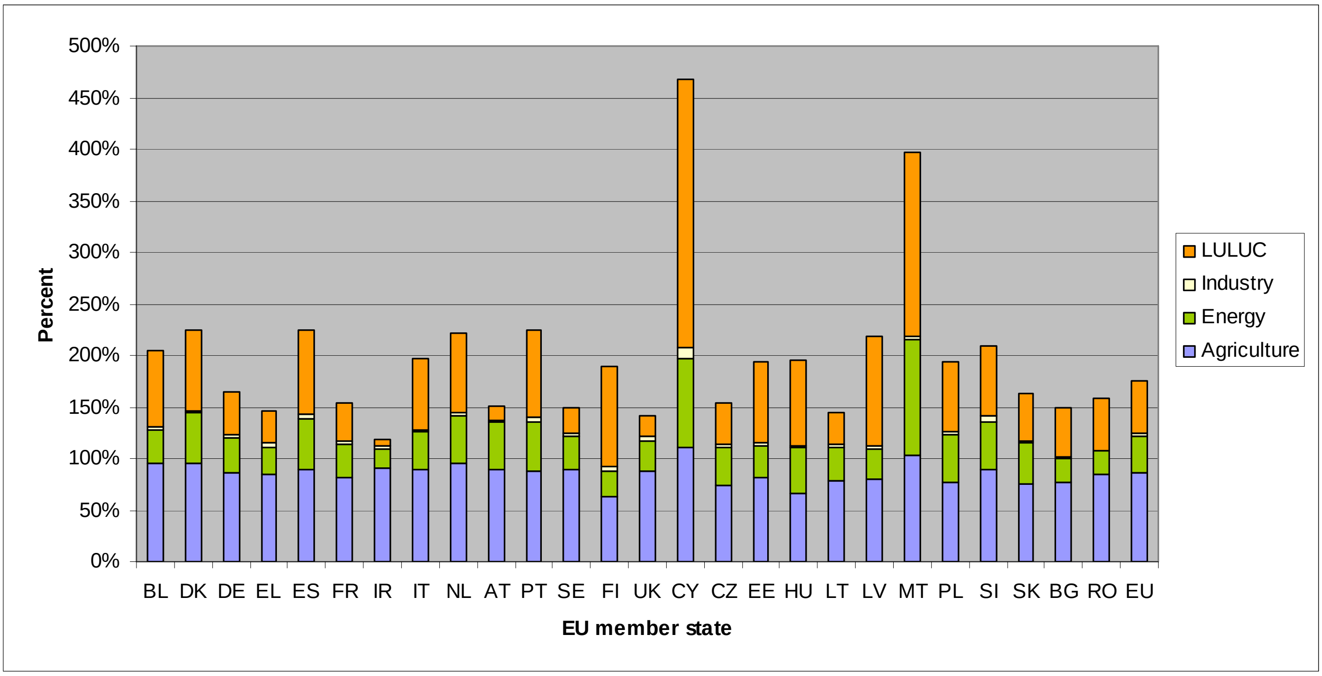


Figure 6.26: Total GHG fluxes of EU livestock production (CAPRI LCA results) in relation to total agricultural production (CAPRI activity based results)

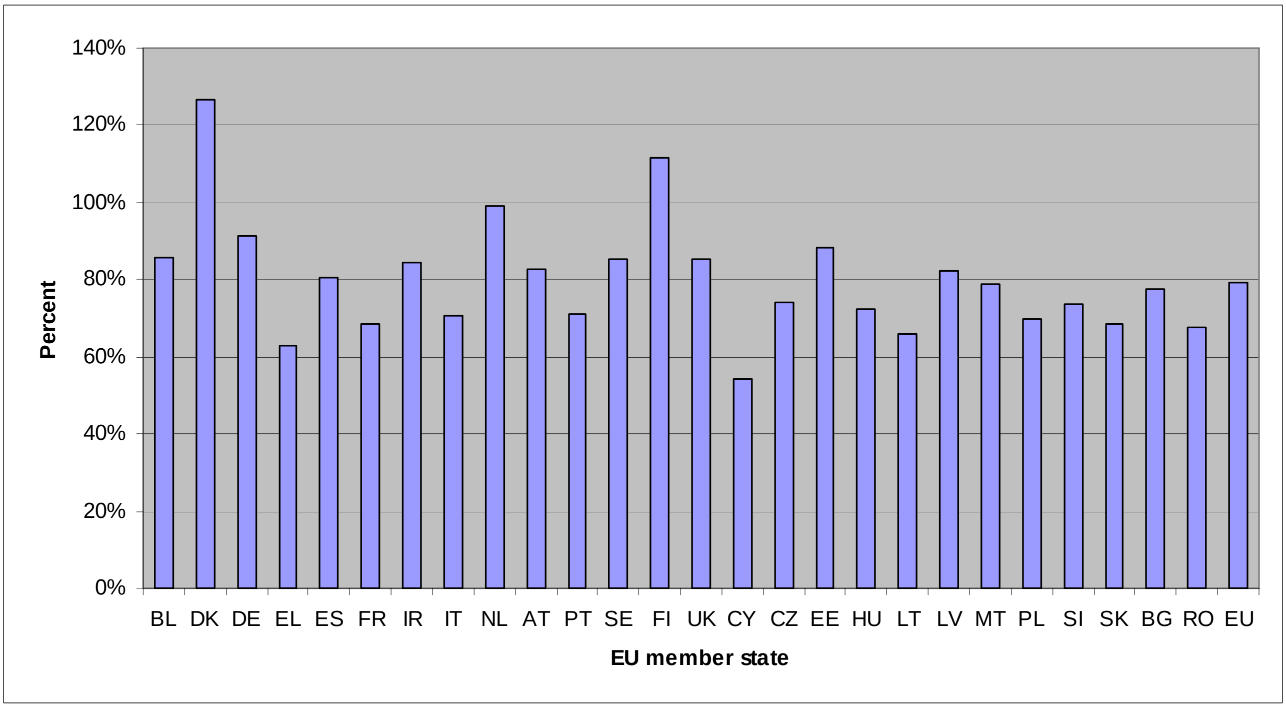


Figure 6.27: Total GHG fluxes of EU agricultural production (CAPRI activity based results in relation to National Inventories)

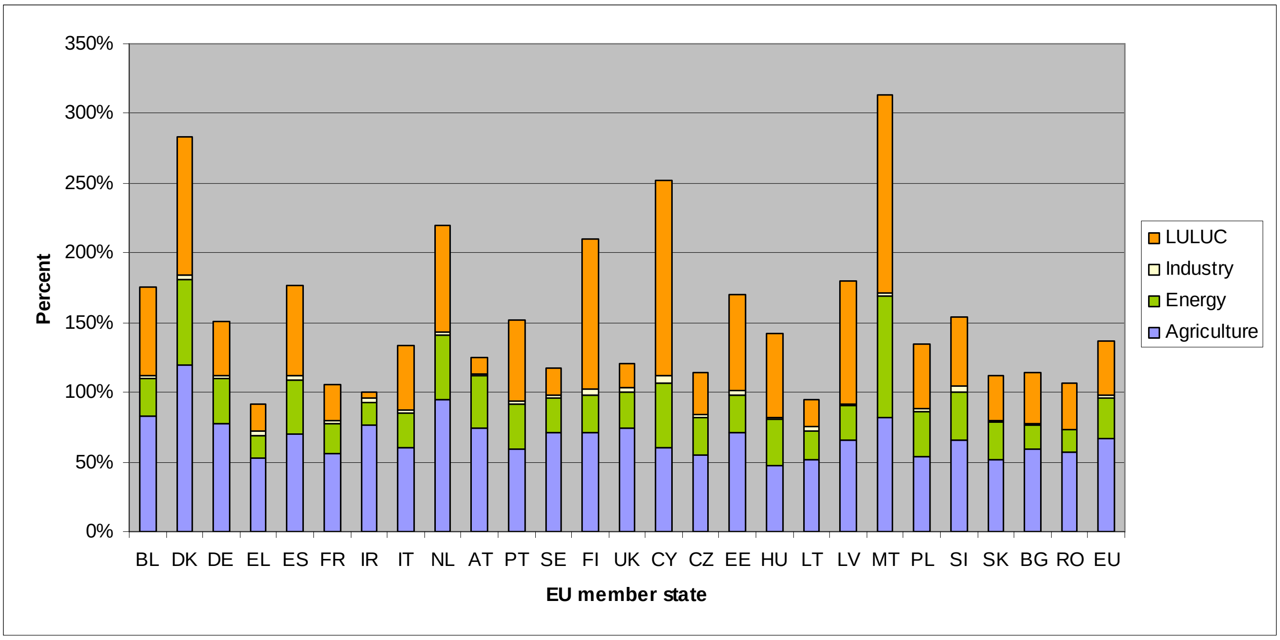


Figure 6.28: Emissions of the EU livestock production from the agricultural sector (CAPRI LCA based results) in relation to emissions from EU agricultural production (National Inventories)

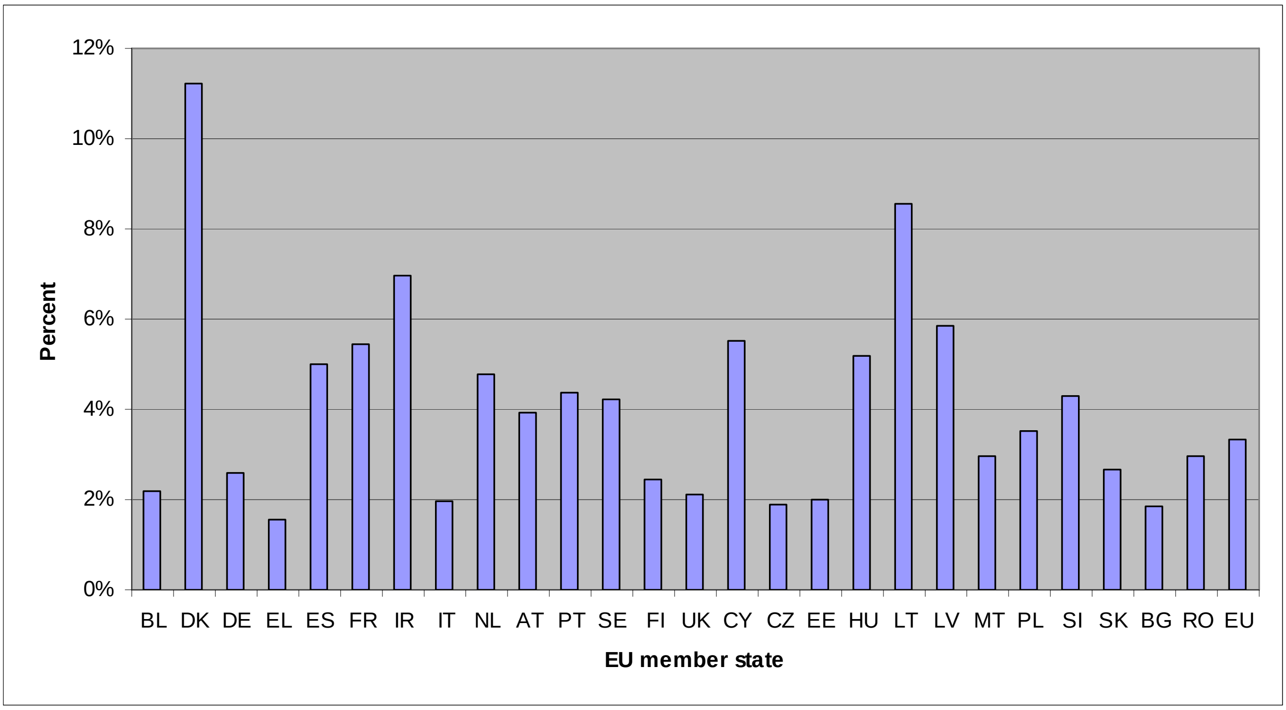


Figure 6.29: CO_2 emissions from energy use in EU livestock production (CAPRI LCA based results) in relation to emissions from EU energy use (National Inventories)

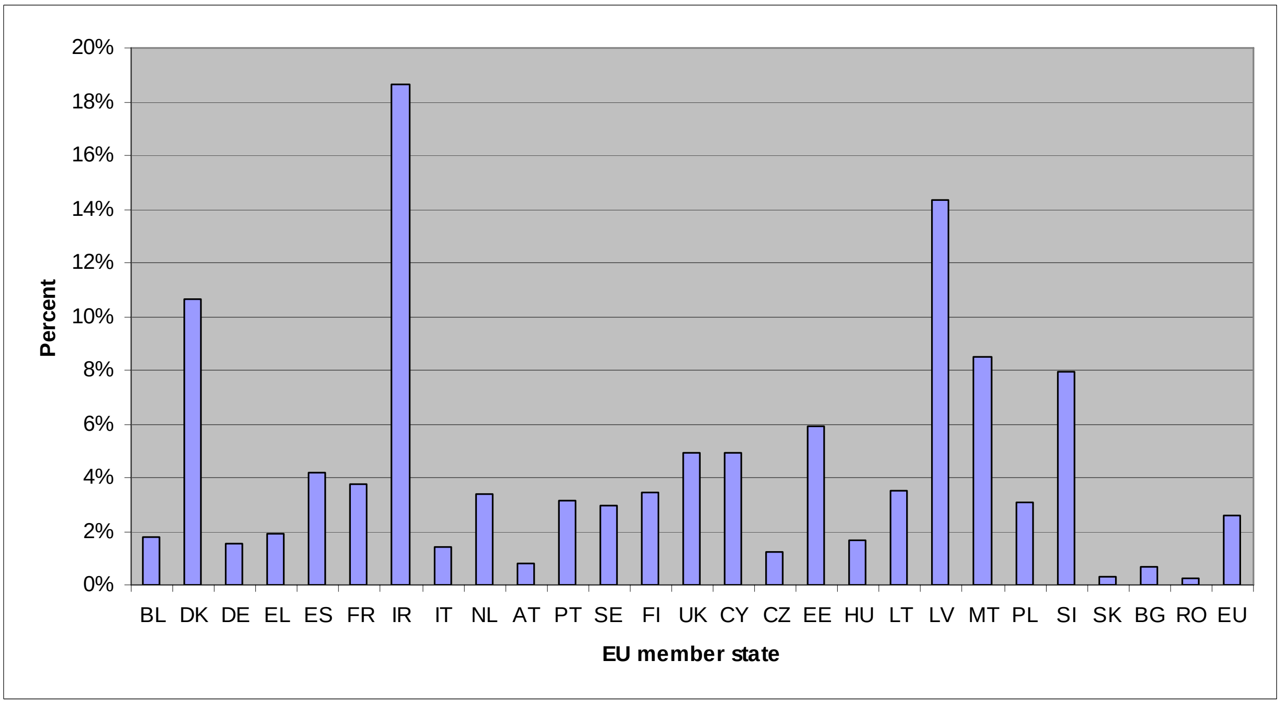


Figure 6.30: CO_2 emissions from industries in EU livestock production (CAPRI LCA based results) in relation to emissions from EU industries (National Inventories)

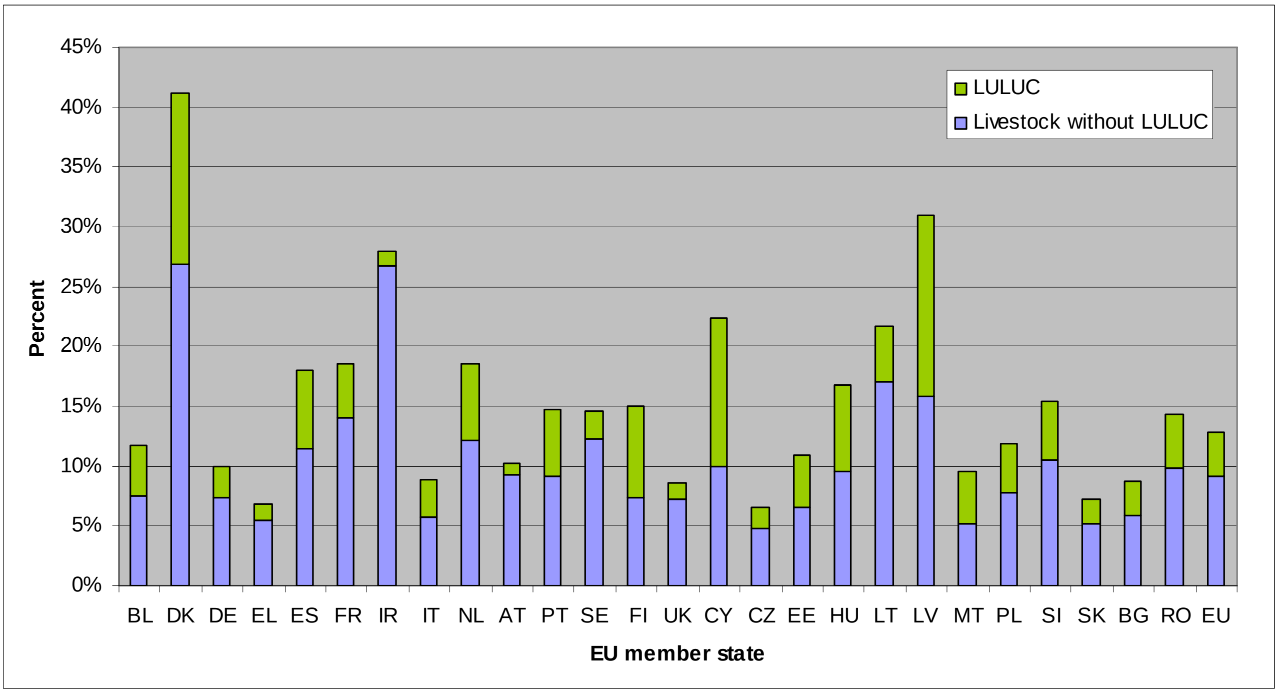


Figure 6.31: Total GHG fluxes of EU livestock production (CAPRI LCA based results) in relation to EU total GHG emissions (National Inventories)

6.7. Summary

The product based emissions presented in this Chapter are based on the activity based emissions presented in chapter 5. However, for several reasons the total of product based emissions usually does not exactly reproduce the total of activity based emissions. First, as mentioned above, for some emission sources the product related emission factors do 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. Secondly, the different focus of a product and process related approach can lead to deviating results, since animal products are not always produced in one year, and so variations of production from year to year can lead to different assignments of emissions in the time dimension.

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 19 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 chapter 3). The base year for the estimation is 2004.

According to CAPRI calculations total GHG fluxes of European Livestock production amount to 661 Mio tons of $CO_{2\text{-eq}}$ 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, 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. 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). 181 Mio tons (27%) 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). 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%.

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%), due to low efficiency and high LULUC-emissions.

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 (1 kg) and Ireland (1 kg), the highest in Cyprus (2.8 kg) and Latvia (2.7 kg).

7. TECHNOLOGICAL ABATEMENT MEASURES FOR LIVESTOCK REARING EMISSIONS

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7.1. Introduction

This chapter reviews the potential of GHG reductions with technological measures in the EU livestock sector, as identified in peer-review literature, and then presents a quantification of a selection of these measures using the CAPRI model. Before analyzing the potential for mitigating actions in any of the sectoral activities related to livestock, it is important to quantify as much as possible their magnitude and importance, both in relation to the global picture, as well as within the agricultural sector. As discussed in the agriculture mitigation chapter of IPCC AR4 (IPCC, 2007), a distinction exist between theoretical, technical and economic mitigation potential. The first is simply a quantified upper limit to maximum achievable reductions, further limited by available technological options. Economic mitigation potential provides an additional subset of options, depending on cost. This chapter focuses on technical mitigation potentials only. Chapter 7.2 offers a review of emission reduction factors for technological measures related to livestock production in Europe, based on an extensive review of literature data. Chapter 7.3 proceeds to analyze the likely impact and actual GHG reduction potential of selected technological measures for which sufficient quantitative information was available. The calculations are carried out with the CAPRI model used also in the previous sections.

Official data shows that total GHG agricultural emissions for the EU27 were 462 Mt $CO_{2\text{-eq}}$ yr^{-1} in 2007 (EEA, 2009). They were dominated by N_2O emissions from soils (234 Mt $CO_{2\text{-eq}}$ yr^{-1}, i.e., more than 50%); CH_4 from enteric fermentation (145 Mt $CO_{2\text{-eq}}$ yr^{-1}, about 33%); CH_4 and N_2O from manure management (87 Mt $CO_{2\text{-eq}}$ yr^{-1}, 19% of total).

To put these figures in perspective with current and potential future EU-ETS and Kyoto Protocol requirements, the current 2008-2012 Kyoto cap (i.e., 8% below 1990 levels) implies reductions of roughly 500 Mt $CO_{2\text{-eq}}$ yr^{-1} for EU27, with respect to the 1990 baseline. These reductions would at least be two and a half times as large in 2020[6], i.e., about 1.2 Gt $CO_{2\text{-eq}}$ yr^{-1}, if EU commitments of -20% cuts by 2020 were implemented. If the agriculture contribution to such cuts were computed in proportion to its role within global EU emissions—i.e., about 10%—then required cuts in agricultural GHG emissions would be about 50 Mt $CO_{2\text{-eq}}$ yr^{-1} for the 2008-2012 commitment period, and about 120 Mt $CO_{2\text{-eq}}$ yr^{-1} by 2020.

The EC-GHG inventory for agriculture (EEA, 2009; 2010) identifies three key categories, i.e. CH_4 emissions from enteric fermentation, CH_4 and N_2O emissions from manure management, and N_2O emissions from agricultural soils.

[6] Assuming no growth in EU global and agricultural emissions in 2020 from current levels

According to the national inventories for the year 2007 (EEA, 2009) and in terms of agricultural land use, crops are responsible for more than two-thirds of all direct and indirect N_2O emissions from soils (152 Mt CO_{2-eq} yr^{-1}), while pasture grassland and dry paddocks are responsible for the remainder third (42 Mt CO_{2-eq} yr^{-1}). Chapter 6 showed that more than half of soil emissions in agriculture are to be attributed to livestock productions. Enteric fermentation emitted one-third of all GHG emissions from agriculture (EEA, 2009), or 145 Mt CO_{2-eq} yr^{-1}. Key sources are emissions from cattle (roughly 80% of total) and sheep, with dairy and non-dairy cattle totalling 55 and 65 Mt CO_{2-eq} yr^{-1}, respectively. Manure management was responsible for GHG emissions in EU agriculture of about 87 Mt CO_{2-eq} yr^{-1}, roughly 19% agricultural emissions. Methane gas, emitted from anaerobic digestion in storage systems, represents over two-thirds of the emissions, at 55 Mt CO_{2-eq} yr^{-1}, with the remainder produced as N_2O gas, at 32 Mt CO_{2-eq} yr^{-1}. Emission data can be analyzed by either animal type or animal waste management system (AWMS). For instance, cattle livestock dominates overall GHG emissions, being responsible for 46% of the total (40 Mt CO_{2-eq} yr^{-1}) – followed closely by swine (35 Mt CO_{2-eq} yr^{-1}). Poultry emits 9% of total GHG emissions in AWMS (8 Mt CO_{2-eq} yr^{-1}).
As for CH_4 sources in AWMS, swine is the first emitter (29 Mt CO_{2-eq} yr^{-1} as CH_4), followed by cattle (22 Mt CO_{2-eq} yr^{-1} as CH_4). In terms of N_2O sources in AWMS, cattle livestock is by far the largest emitter (18 Mt CO_{2-eq} yr^{-1} as N_2O), followed by swine (6 Mt CO_{2-eq} yr^{-1} as N_2O) and poultry (5.5 Mt CO_{2-eq} yr^{-1} as N_2O). Finally, 88% of emissions in AWMS are produced in solid storage and dry lot systems.

How much of this amount could be mitigated? Judicious application of fertilizer, whether organic or inorganic, including a combination of reduction in application rates and timing would maintain yields while reducing N runoff (IPCC, 2007a). Such a mitigation strategy is already being implemented in the EU, by means of the 1991 EU Nitrates directive. Current regulations only apply to nitrates vulnerable zones (NVZ) on an obligatory basis. Therefore, a good mitigation strategy in the EU would be an extension of the NVZ requiring a balance between fertilizers application and crop needs on all agricultural land—with obvious positive impacts on nitrates leaching, ammonia and N_2O emissions. An additional strategy would be the extension of nitrification inhibitors in fertilizer products (e.g., Commission Regulation (EC) No 1107).

Emissions from enteric fermentation, within each animal category, are related directly to the number of livestock and their type, and so is mitigation potential. The largest emitters per animal type remain cattle, with emission ranges of 50-100 kg CH_4 $head^{-1}$ yr^{-1}. Reductions in enteric fermentation could likewise be achieved by changes in animal diet, as discussed in following sections.

GHG emissions from AWMS can be mitigated indirectly, by reducing animal numbers, as well as directly, by implementation of a series of technical solutions altering modalities of collection, storage and disposal within and across AWMS. In general the methane component of these emissions can be captured and flared in large proportions, for power or otherwise.
However, uncertainties abound concerning the effects of significant methane capture, specifically on: a) Quality of treated waste for subsequent field applications; b) Dynamics of N_2O emissions following application of the treated waste.

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, 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. Such a study would go beyond the time frame of this project however. The simpler approach followed herein was to review peer-reviewed estimates of emission reduction potentials that have been made in different EU countries and use these estimates as a proxy for livestock systems throughout Europe, in order to have a first consistent set of values to be used in CAPRI.

7.2. Emissions reduction factors for technical measures to reduce GHG emissions related to livestock production in Europe

This section compiles a list of specific, available management techniques across all agricultural subsectors, which could be implemented to achieve GHG mitigation in the EU. Special attention is given to the three key subsectors identified previously, i.e., emissions from soils; enteric fermentation; and manure management, or animal waste management systems in general, AWMS. The data reported herein are from literature and web search, including information from the EU PICCMAT project on "Agriculture and climate change: mitigation, adaptation, policy changes (PICCMAT, 2010).

7.2.1. Soil Emissions

Several studies have focused on improved grassland management as a means to reduce emissions of N_2O from agricultural soils. As the N_2O emission factor is higher compared to cropland, so that action in this subsector is particularly effective.

At the same time, data on impacts of different grazing strategies and changes in grassland management more in general are scarce and very uncertain (IPCC, 2007a).Recent research on nitrification inhibitors indicates high potential to reduce N_2O emissions by roughly 30% in the field. However the overall systems results of inhibitors are not well understood. More in general, it is not clear to what extent managing a pasture system for reduced N_2O emissions from soils would also lead to overall GHG emission reductions of the underlying ecosystem (IPCC, 2007a). For this reason, few of the technical actions specified below come with a quantified reduction potential; in most cases, the impact of the suggested mitigation action is only “positive” or “negative”, so that results were not used in subsequent CAPRI model estimates (see Table 7.1).

Reduced grazing intensity, or more specifically management towards recovery of overgrazed systems, may lead to improved soil conditions, with positive effect on both N_2O emissions and soil organic carbon. Yet when grazing does not trespass a certain point, it may stimulate root and vegetative growth, increasing SOC. The degree to which such strategies may be successful in terms of their overall GHG balance depends heavily on many interacting factors however, such as climate regimes, and especially the associated changes in soil N inputs. For instance, extensification was found to turn grassland into a carbon sink instead of a source (Soussana et al., 2002; Tab. 3/23).

Bakken (1994) however found that, although soil C emissions were reduced in low-grazing compared to intensive systems, GHG emissions/unit of milk produced were similar between the two systems (Tab. 3/25). Furthermore, increasing grazing intensity can actually increase soil C in wet systems --although the higher fertilizer applications associated with these systems need also to be considered

In some cases, for instance in the Netherlands, it was found that emission of N_2O from stable, storage and application of manure was less than emission during grazing. Therefore a mitigation action specific to that location and management type can be developed by focusing on shortening grazing times, leading to a decrease of total emission of N_2O from soils (Velthof et al., 2000; Tab 3/24).

Ploughing permanent grassland releases significant amounts of CO_2 and N_2O. Re-scheduling ploughing activities to different parts of the year, may under specific circumstances reduce emissions of N_2O whenever more efficient plant uptake of the released soil N is achieved (e.g., Vellinga et al., 2004; Tab. 3/27).

Similarly, moving from wide-area ploughing to limited area ploughing, i.e., leaving unproductive areas un-ploughed, can reduce overall soil emissions. Finally, instead of improving grass production by ploughing and re-sowing, sowing new seeds under a no-till system may effectively reduce soil emission of N_2O related to this disturbance (Vellinga et al., 2000; Tab. 3/29-30).

In terms of reducing emissions form manure applications, trail hose application in combination with immediate shallow incorporation is the most effective way of reducing N_2O emission from application of manure on arable land. Immediate shallow incorporation of fermented slurry applied with trial hose gives a decrease in emission of methane in comparison with no incorporation (Wulf et al., 2002; Table 3/1-2). Data indicate that, compared to direct injection, N_2O emissions were reduced by -50%. However NH_3 emissions would increase instead.

As found for grasslands, limiting cropland applications of manure in autumn, when fewer crops are present and growth rates are lower than in spring, decreases overall N_2O losses from fields and reduces emissions from crop residues. Depending on cropping system and climate regime, technical mitigation potentials range from -8% to -40% (Oenema et al., 2001).

Meta analysis of SOC accumulation rate and potential carbon mitigation for Europe of two levels of animal manure input, and effect of applying all manure to arable land rather than grassland - increases SOC accumulation and reduces N_2O from manure (Smith et al., 2000; 2001).

Nutrient leaching, a major source of N_2O losses to the atmosphere, could be reduced by using catch crops, such as energy crops as buffer strips along open streams, and wind erosion could be reduced by using Salix plantations as shelterbelts (Borjesson, 1999).

Finally, it is estimated that an integrated approach that includes more efficient use of fertilizer and changes in the application of animal manure can lead to reductions in N_2O emissions of -5% to -15% (Oenema et al., 2001; Trends in global nitrous oxide emissions from animal production systems. Table 3/14)

7.2.2. Enteric Fermentation

Emissions from enteric fermentation of livestock can be reduced with actions focusing on health, maintenance and performance of the animals. To this end, diet components can be changed significantly (crude fibre, N-free extract, crude protein and ether extract) so that methane emission due to enteric fermentation might decrease
However, such actions based on overall diet efficiency of livestock may be only relevant for developing countries, as feeding regimes in developed countries are already optimized (Clemens, 2001).

On the other hand, actions focusing on alteration of bacterial flora, including removal of ruminant protozoa, as well as cattle breeding for minimizing methane production, can be an effective strategy towards reducing GHG emissions from this sub-sector (FAL, 1992; Clemens, 2001; Tab. 3/15-20).

Additives in feed are being explored towards limiting enteric fermentation. However their use is currently limited by negative effects on milk production (Oenema et al., 2001).

Changing animal diet can have positive effects on reducing methane emissions form fermentation. For instance, changing diets from grass to maize (up to a maximum of 75% of needed energy intake from grass) may decrease methane from enteric fermentation (Kuikman et al., 2003).

An increase of lactations per cow has the potential to reduce methane emissions by -10%, because heifers emit greenhouse gases without producing milk (Weske, 2006).

The studies reviewed above indicate an overall technical potential between -5% and -10%.

7.2.3. Animal Waste Management Systems

While there is limited amount of data relative to GHG mitigation of emissions from agricultural soils and from enteric fermentation, many more exist in relation to actions that can be applied to manure management, and in general to AWMS.

7.2.3.1 Composting

Composting cattle manure by aerating storage containers using porous membranes and ventilation pipes reduces CH_4 emissions compared to storage as slurry (-30%) or stockpile (-70%). However the same treatment increases N_2O emissions, albeit by uncertain amounts; overall net GHG mitigating effects are found (Pattey et al., 2005).

Indeed, GHG emissions may also be reduced if all manure stored as slurry and stockpile were composted using the passively aerated window system. Another option would be collecting and burning the CH_4 emitted by the manure (Pattey et al., 2005).

Furthermore, increased straw content may significantly reduce emissions during composting. In deep litter from fattening pigs, this method reduced virtually all CH_4, and N_2O emissions (Sommer et al., 2000).

Composting slurry with or without other organic material and transforming the biogas into heat and/or electricity will avoid emissions of CH_4 and N_2O from storage, reducing them by up to -95%. Besides the process will decrease the emission of CO_2 emissions by fossil fuel substitution (Mol et al., 2003).

7.2.3.2 Compaction and Coverage

Manure compacting and coverage may limit GHG emissions. For instance, cattle farmyard manure was compacted by driving over it and then covered in plastic sheeting. Comparisons to uncovered heaps confirmed reductions of CH_4, though N_2O emissions may increase depending on weather conditions (Chadwick, 2005). Covering solids storage, separated from pig slurry, considerably reduced emissions of CH_4 and N_2O, up to -80% to -90% compared to no coverage (Hansen et al., 2006; Tab. 3/4-5).

Similarly, slurry tanks are sources of methane, and permeable surface covers (natural crusts or artificial covers) can reduce methane emissions through microbial transformations and methane oxidation. A cover may be a natural surface crust or an artificial barrier. Significant reductions of CH_4 may occur, ranging from -20% to -80% across studies. However, ammonia will diffuse into the surface crust; the resulting nitrification and denitrification may lead to increased N_2O emissions. There are few investigations and results are therefore uncertain (Petersen et al., 2005; 2006; Bicudo et al. 2004; Berg, 2006).

7.2.3.3 Temperature of storage tanks

Emissions from slurry stored inside can be reduced by moving storage tanks outside, even if in a temporary fashion. For instance, storage in Scandinavian countries is at much higher temperatures compared to outside for most of the year. This will result in higher methane emissions from in-house stored slurry, and frequent removal to outside will reduce emissions, up to -35% (Sommer et al., 2004). The same technique, i.e., taking advantage of lower outside temperatures, was successfully tested in the Netherlands. (Oenema et al., 2001, Table 3/8).

In addition, when moving storage outside is not possible or not effective, indoor cooling might decrease emission of methane (Haeussermannet al., 2006, Tab. 3/13).

7.2.3.4 Anaerobic digestion

Biogas production is a very efficient way to reduce GHG emissions, both via production of renewable energy and through avoidance of emissions from manure management.
A long digestion should be taken into account in order to avoid emissions at storage and from soil applications afterwards (Clemens, 2006). Technical reduction potential is about -90% for CH_4 and -30 to -50% for N_2O.

Emissions can be reduced by anaerobic digestion of slurry with methane capture and use for electricity and heat generation—and fossil fuel substitution. In addition, the digested manure has lower potential for CH_4 emissions from storage –and for N_2O from field applied manure (Sommer et al., 2004).

7.2.3.5 Slurry Removal from Stables

Slurry removal between fattening, in combination with cleaning the slurry pit decreases methane emission from stables of up to -40%. Of course mitigation strategies localized at housing level require further effective slurry management and treatment down the "production" chain, i.e., in order to avoid increased methane emissions afterwards, for instance in field manure applications (Haeussermann et al., 2006).

7.2.3.6 Summary

A large number of studies have focused on manure management, indicating that a great potential for mitigation exists across a range of solutions. 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 appears to be about 30% of current emissions from manure management, provided anaerobic digestion and composting are key components of such strategies.

7.2.4. Conclusion

Technically achievable mitigation solutions in the EU livestock sector, based on the data reviewed herein, would amount to reductions of 55-70 Mt $CO_{2\text{-eq}}$ yr^{-1}, i.e., 15-19% of current GHG emissions. The mitigation solutions discussed herein help EU agriculture to contribute significantly to overall GHG mitigation efforts. The literature reviewed also suggests that additional technical mitigation can be achieved, in particular in soil and enteric fermentation, suggesting that more research is needed in these areas. At the same time, simulations carried out with coupled farm productivity/economic models can better identify key bottlenecks in specific mitigation strategies and strategies to overcome them. The timeframe to implement the measures outlined in Table 7.1 is also relevant – especially in the context of a 2020 target previously discussed. 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.

Table 7.1: Technical Mitigation Options in Agriculture Related to Livestock. Often only one or very few peer-reviewed experimental studies were available as documentation for the effects assumed

#	Activity	Practice	Strategy	CH_4	N_2O	Tradeoffs	References
1.	Manure Biosolid Management	Co-fermented Slurry Application	Shallow incorporation of co-fermented slurry. Cattle	-55 % in comparison with injection but an increase in comparison with splash plate	-65% in comparison with injection	N: Increase in ammonia emissions	Wulf et al., 2002
2.	Manure Biosolid Management	Manure Application	No application in autumn. Cattle		Lower from crop residues: -20% cereals; -40% sugar beet; -8% others	P: more manure available during growing season; less leachates	Oenema et al., 2001
3a 3b	Manure Biosolid Management	Storage	Composting	Much less -30% compared to slurry -70% compared to stockpile	More compared to stockpile Much More compared to Slurry		Pattey et al., 2005
4.	Manure Biosolid Management	Storage	Compacting and Coverage	Less	Less		Chadwick, 2005
5.	Manure Biosolid Management	Storage	Increased Straw Content for composting. Pig	-99% Emissions reduced from 191.6 to <0.1 g C/ton fresh weight in manure Compared to composting with less straw content	-99% Emissions reduced from 58.6 to <0.1 g N/ton fresh weight in manure Compared to composting with less straw content		Sommer et al, 2000
6.	Manure Biosolid Management	Storage	Covering Manure Solids Pigs	-88%	-99%	P: -12% NH_3	Hansen et al., 2006
7. 7b	Manure Biosolid Management	Storage	Covering Slurry Tanks	-20-40% -30-80%	Uncertain; may increase	P: -80% NH_3	Petersen et al., 2006; Petersen et al., 2005; Bicudo et al, 2004 Berg, 2006
8.a 8b	Manure Biosolid Management	Storage	Moving inside/outside location of Slurry Tanks	-35% compared inside storage	Not reported		Sommer et al., 2004 Oenema et al., 2001

#	Activity	Practice	Strategy	CH_4	N_2O	Tradeoffs	References
9.a 9b 9c	Manure Biosolid Management	Treatment	Anaerobic digestion and biogas	-90-95% from storage of digested slurry, provided the residual methane is captured and flared	-30% to -50% N_2O emissions from field applications of digested slurry		Sommer et al., 2001; Sommer et al., 2004; Oenema et al. 2001; Clemens, 2006
10a.	Manure Biosolid Management	Management	Field Capture with dedicated crops alongside streams				Borjesson, 1999
10b.	Manure Biosolid Management	Applications	More efficient use of manure	less	Less, but in some cases may increase		Smith et al., 2000; Smith et al., 2001
11.	Manure Biosolid Management	Slurry management	Composting with or without organic material	-95%	-95%		Mol et al., 2003; Kuikman et al., 2004
12.	Manure Biosolid Management	Slurry management Pigs	Slurry removal from stable	-40% of stable emissions. Requires further action at treatment level to maintain gain.	Not reported		Haussermann et al., 2006
13.	Manure Biosolid Management	Slurry management Pigs	Indoor cooling	Less	Not reported	N: Increased energy use	Haussermann et al., 2006
14.	Arable Land	More efficient use of fertilizer, including manure applications	N-use efficiency imprevements	- 5-15%	-5-15%		Oenema et al., 2005
15.	Animal Husbandry	Diet	Optimizing Diets	Less	None		Clemens, 2001.
16.	Animal Husbandry	Diet	Reduction of bacterial flora and breeding	-30% per litre milk produced	None		FAL, 1990; Clemens, 2001.
17.	Animal Husbandry	Diet	Additives in Feed	less	None	N: negative impacts on milk production	Veen, 2000; Oenema et al., 2001
18.	Animal Husbandry	Diet	Increase maize share in diet	-5%	None	N: indirect emissions from maize cultivation	Kuikman et al., 2003
19.	Animal Husbandry	Farm Strategies	Reduce animal numbers by improving health	Less, in proportion with animal numbers	Less, in proportion with animal numbers		Velthof et al., 2000; Velthof et al., 2003

#	Activity	Practice	Strategy	CH_4	N_2O	Tradeoffs	References
20.	Animal Husbandry	Farm Strategies	Increase lactations per cow	-10%	Not reported		Weske, 2006
21.	Animal Husbandry	Housing Systems	Slurry vs. straw based housing system	No change	No change		Amon, 2001
22.	Grassland Management	Production	Reduced intensity of grazing/Exentification	From source to sink (of overall CO_2e)	From source to sink (of overall CO_2e)	P: from overall source of CO_2e to sink	Soussana et al., 2001; Soussana et al., 2007
23.	Grassland Managment	Grazing	Reduced Grazing periods Limiting grazing during dry periods	increased	Reduced		Velthof et al, 2000; Kuikman et al., 2004
24.	Grassland Managment	Grazing	Switch from high tot low intensity	reduced	Reduced	P: -30% of CO_2 eq. emissions. N: same emissions per unit milk produced	Bakken, 1994
25. 25.b 25.c	Grassland Management	Grazing	Reduced intensity Recovery of overgrazed systems	Not reported	Not reported	P: increase in soil C sequestration Due to less disturbance; root growth stimulation, Erosion prevention	Conant, 2002; Bohem, 2004
26.	Grassland Management	Ploughing	Shifting timing of grassland restoration (from autumn to spring); no autumn and winter ploughing	Not Reported	-50%		Vellinga et al, 2004
27.	Grassland Management	Crop rotations	Reduce time with crop rotations on grassland	Reduced	Reduced		Van der Pol, et al., 2002
28.	Grassland Management	Ploughing	Avoid wide-area ploughing	Reduced	Reduced		Vellinga et al., 2000
29.	Grassland Management	Ploughing and sowing	Sow in present grassland w/o ploughing	Not reported	-100%		Vellinga et al., 2000

7.3. Quantification of the potential for reduction of GHG and NH_3 emissions related to livestock production in Europe with technological measures

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7.3.1. Introduction

Based on the methodology presented in chapter 4 (in particular the nitrogen model based on the MITERRA methodology) and on estimated GHG reduction factors of selected technological measures presented in section 7.2 (see Table 7.1) a quantification of the technological potential for the reduction of GHG and NH_3 was carried out with the CAPRI model for the production structure of the base year 2004. In the following we use the following definition: "The technical reduction potential of a measure is defined as the reduction (or increase) of emissions, compared to the emissions calculated in the reference situation, if the measure would be applied on all farms". The reference situation in our case is the base year presented in chapter 6. Therefore, the potential must not be interpreted as an estimation of the real reduction for a measure, as the implementation rates of the respective measures are unknown. Generally, data on technologies actually applied in European agriculture are hardly available. Therefore, with the exception of the nitrogen model, the calculation methodology of CAPRI (see chapter 4) is generally not based on very detailed knowledge on technologies as this might be the case for detailed farm models at a limited regional scope. This kind of information would be required if dealing with some of the very specific technologies presented in Table 9.3.

The selection of technological measures for which a quantification of the emission reduction potential was carried out was mainly based on the availability of reduction factors (for all gases) and the applicability of the available information to the CAPRI model. Therefore, the selection should not be interpreted as a ranking in terms of reasonability or feasibility of the measures. For the NH_3 emission reduction potential we selected most of the technological measures or measure groups from the MITERRA and GAINS projects, since the reduction factors are based on a thorough analysis of technological options and they are implemented in the CAPRI model. From the list of measures presented in section 7.2 we have only selected a few examples for the quantification of the GHG emission reduction potential. This is due to different reasons: First, for most technologies information on emission reduction factors is missing at least for one of the considered gases. For example, if for a measure we have information on the reduction factor for methane but we do not know its impact on N_2O or NH_3, it is not possible to estimate an overall reduction potential. Secondly, sometimes the reduction factors found in the literature (see table 7.2) refer to a reference technology which is not equivalent to the reference technology assumed (and quantifiable) in CAPRI. Finally, some of the measures proposed in section 7.2 refer to changes of livestock herds, feed diets or production intensities. Those are endogenous parameters in CAPRI and a change of it is not easily possible.

The following technological scenarios have been selected for the quantification of the emission reduction potential:

- 100% Animal House adaptations
- 100% Covered outdoor storage of manure (low to medium efficiency)

- 100% Covered outdoor storage of manure (high efficiency)
- 100% Low ammonia application of manure (low to medium efficiency)
- 100% Low ammonia application of manure (high efficiency)
- Urea substitution by ammonium nitrate for mineral fertilizer application
- No Grazing of animals
- Biogas production for animal herds of more than 100 LSU (livestock units)

7.3.2. Technological scenarios

7.3.2.1 100% Animal Housing adaptations

Design modifications of animal houses are a possibility to reduce emissions of NH_3. This can be achieved if either the surface area of the slurry or manure exposed to the air is reduced or the waste is frequently removed (e.g. flushed with water or diluted with formaldehyde) and placed in covered storages. The scenario includes different control options for various livestock categories. Ammonia emissions from cattle housing can be reduced through regular washing or scraping the floor, frequent removal of manure to a closed storage system and modification of floor design. For pig housing an emission reduction can be obtained by combining good floor design (partly slatted floor, metal or plastic coated slats, inclined or convex solid part of the floor) with flushing systems. In case of laying hens manure can be dried, either through the application of a manure belt with forced drying or drying the manure in a tunnel. For other poultry emissions can be reduced by regularly removing the manure using a scraper or continuously blowing heated air under a floating slatted and littered floor to dry the litter. The assumed emission reduction factors are presented in Table 4.8 in chapter 4. For a more thorough discussion of the measures see Klimont et al (2004) and Velthof et al (2007).

If animal housing adaptation measures were implemented in all farms, NH_3 emissions could be reduced by 290 thousand tons (-13%) of N in EU-27. The net reduction is the result of a 311 thousand tons reduction in emissions from manure management, and a 21 thousand tons increase in emissions from manure application. 81 thousand tons could be saved in the production of beef and cow milk, 111 thousand tons in the production of pork and 98 thousand tons in the production of poultry meat and eggs (see Figure 7.1). In contrast to NH_3-emissions, GHG emissions would increase by 82 Mio tons (+12%) of $CO_{2\text{-eq}}$ compared to the base scenario II (see chapter 6), due to an increase of N_2O-emissions from manure management in pork, eggs and poultry meat production (see Figure 7.2). The sharp increase of N_2O emissions can be explained by the strong cross effects presented in Table 4.8.

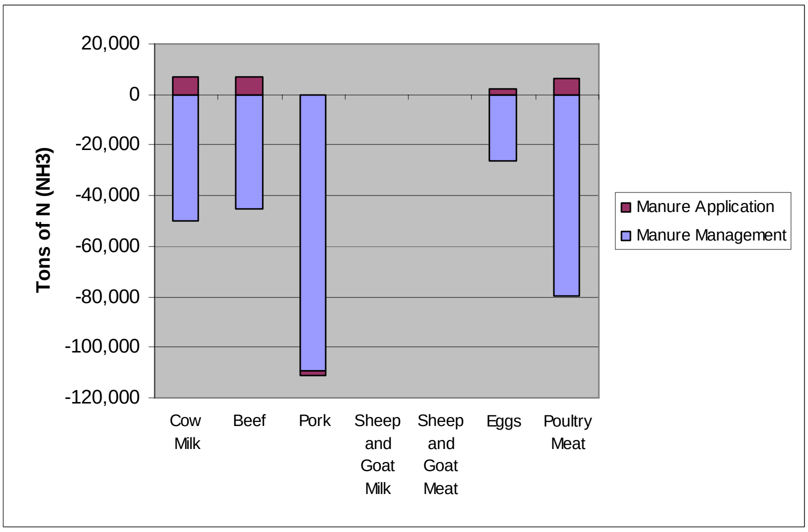

Figure 7.1: NH_3-Emission reduction potential for EU-27 for the scenario '100% Animal House adaptation' in tons of N

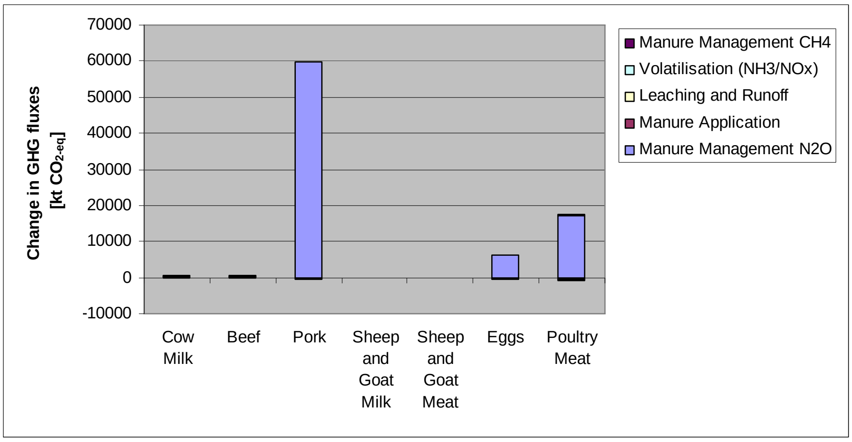

Figure 7.2: Effects on total GHG fluxes for EU-27 for the scenario '100% Animal House adaptation' in 1000 tons of $CO_{2\text{-}eq}$

7.3.2.2 100% Covered outdoor storage of manure

Low to medium efficient storage coverage systems of manure, as defined in the GAINS model, are covers of floating foils or polystyrene, high efficient coverage systems are those using tension caps, concrete, corrugated iron and polyester. The applied emission reduction factors can be found in Table 4.8 in chapter 4.

An EU wide implementation of low or medium efficient coverage systems would reduce NH_3-emissions by 17 thousand tons (-0.7%) of N, resulting from a 40 thousand tons reduction of emissions from manure management and a 23 thousand tons increase in emissions from manure application. Most of the net reduction is achieved in pork production, while for other products a 100% use of low to medium efficient coverage systems would not have a significant impact on emissions (see Figure 7.3). This is due to the fact, that reductions can only be achieved in liquid systems (see Table 4.8). In contrast, NO_X emissions are reduced both in liquid and solid systems, and therefore the 4600 tons (-7%) of emission reduction potential are more or less equally

distributed between beef, cow milk and pork production (see Figure 7.5). Total GHG fluxes would increase by 1.8 Mio tons (+0.3%) of CO_{2-eq}, coming mainly from a rise of methane emissions from manure management (see Figure 7.7).

The NH_3 emission reduction potential of highly efficient storage covers amounts to 164 thousand tons (-7%) of N, composing of a 236 thousand tons decrease of emissions from manure management and a 72 thousand tons increase of emissions from manure application. Reductions are equally distributed among beef, cow milk and pork production (around 50 thousand tons each), while the potential of poultry meat and egg production is lower (see Figure 7.4). NO_X emissions could be reduced by 10 thousand tons (-16%) (see Figure 7.6). Total GHG fluxes would increase by 2.9 Mio tons (+0.4%) of CO_{2-eq}, 0.9 Mio tons in beef production, 1.2 Mio tons in cow milk production, and the rest in the production of other animal products. The increase is mainly due to additional methane emissions from manure management and N_2O emissions from manure application (see Figure 7.8).

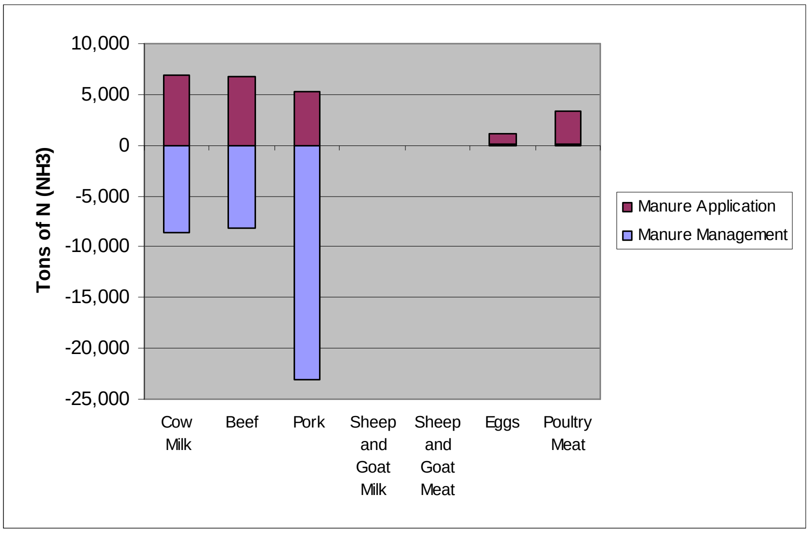

Figure 7.3: NH_3-Emission reduction potential for EU-27 for the scenario '100% Covered outdoor storage of manure (low to medium efficiency)' in tons of N

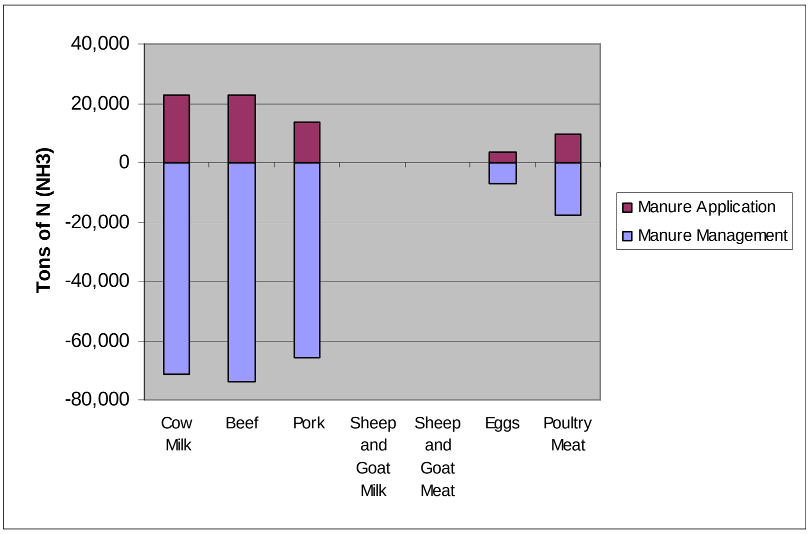

Figure 7.4: NH_3-Emission reduction potential for EU-27 for the scenario '100% Covered outdoor storage of manure (high efficiency)' in tons of N

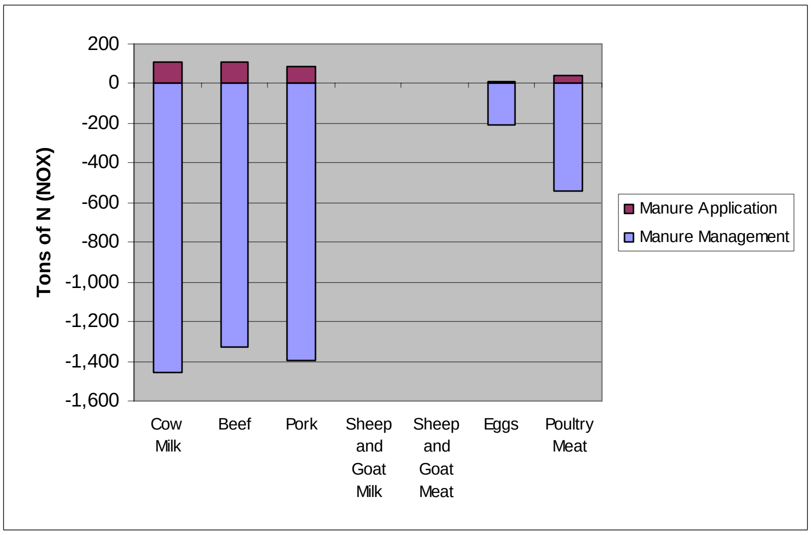

Figure 7.5: NO_X-Emission reduction potential for EU-27 for the scenario '100% Covered outdoor storage of manure (low to medium efficiency)' in tons of N

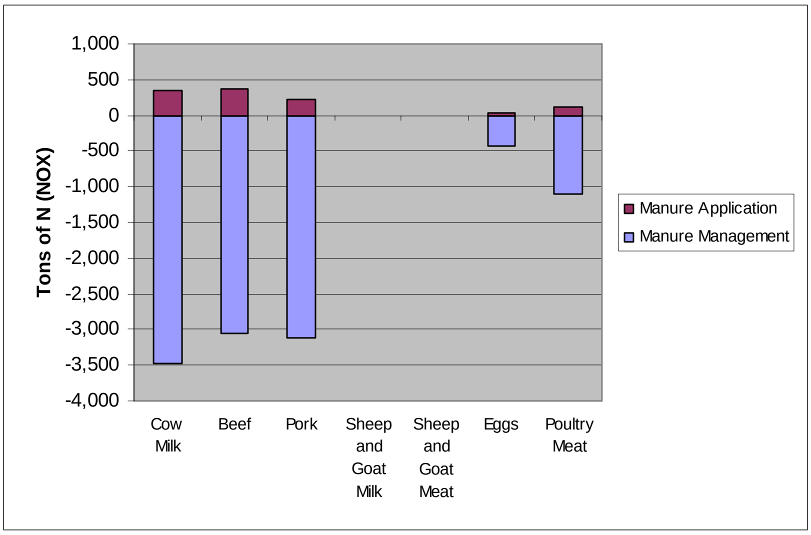

Figure 7.6: NO_X-Emission reduction potential for EU-27 for the scenario '100% Covered outdoor storage of manure (high efficiency)' in tons of N

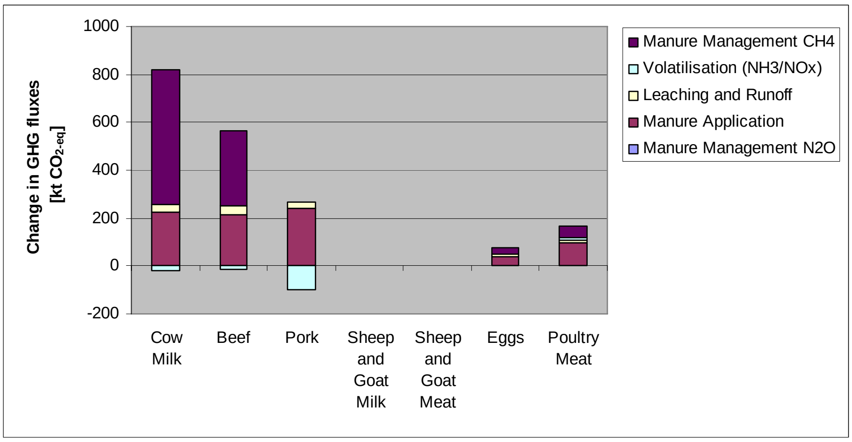

Figure 7.7: Effects on total GHG fluxes for EU-27 for the scenario '100% Covered outdoor storage of manure (low to medium efficiency)' in 1000 tons of $CO_{2\text{-}eq}$

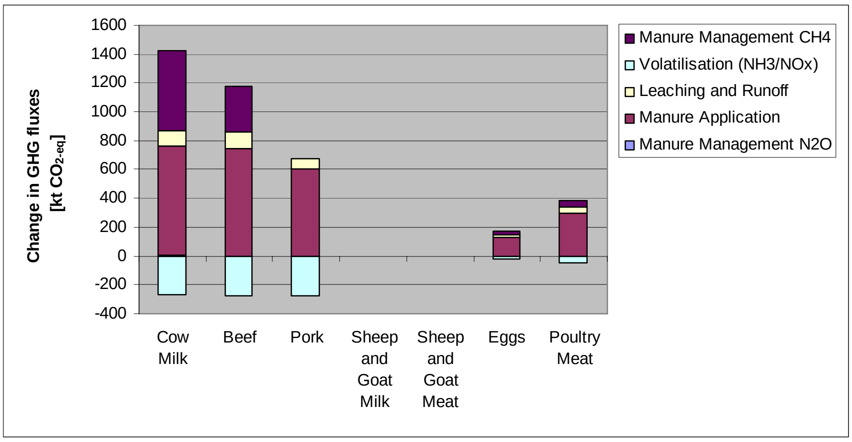

Figure 7.8: Effects on total GHG fluxes for EU-27 for the scenario '100% Covered outdoor storage of manure (high efficiency)' in 1000 tons of $CO_{2\text{-}eq}$

7.3.2.3 100% Low ammonia application of manure

Several techniques can be used in order to reduce the amount of ammonia emissions during and after application of manure to arable land or grassland. In accordance with the GAINS model, CAPRI distinguishes between techniques with high and techniques with medium or low ammonia emission removal efficiency. Techniques with high removal efficiency are immediate incorporation by ploughing (within four hours after application for liquid, and within 12 hours after application for solid manure) and deep and shallow injection of liquid manure. Low and medium efficient techniques are slit injection, trailing shoe, slurry dilution, band spreading for liquid slurry and incorporation of solid manure by ploughing into the soil the day after the application. The emission reduction factors used in the CAPRI model are presented in

Table 4.13 in chapter 4.

A 100% application rate of low ammonia application technologies (low efficiency) in EU-27 could reduce NH_3 emissions by 123 thousand tons (-6%) of N. The reduction potential in first line could be achieved in beef and cow milk production (around 45 thousand tons each) and pork production (29 thousand tons), while the potential for other products is very limited (see Figure 7.9). In case of egg production, due to the high share of high efficient application measures in the base scenario (see

Table 4.15), a 100% application rate of low efficiency measures would even lead to a small increase of emissions. NO_X emissions could be reduced by 2 thousand tons (-3%) of N (see Figure 7.11), while Total GHG fluxes would increase by 9 Mio tons (+1%) of $CO_{2\text{-}eq}$ (see Figure 7.13),

Highly efficient application measures, if adopted by all European farmers, would lead to a reduction of NH_3 emissions by 543 thousand tons (-24%) of N, predominantly in beef (155 thousand tons), cow milk (177 thousand tons) and pork production (134 thousand tons) but also significant shares in poultry meat (54 thousand tons) and egg (17 thousand tons) production (see Figure 7.10).NO_X emissions would decline by 8.5 thousand tons (-13%) of N (see Figure 7.12). Finally, Total GHG fluxes would increase by 21 Mio tons (+3%) of $CO_{2\text{-}eq}$, resulting from rising N_2O emissions from manure application (see Figure 7.14).

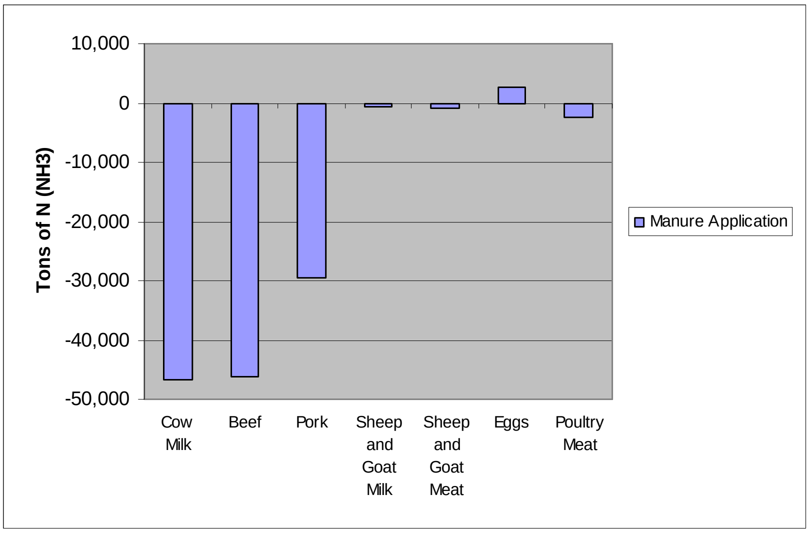

Figure 7.9: NH_3-Emission reduction potential for EU-27 for the scenario '100% Low ammonia application of manure (low to medium efficiency)' in tons of N

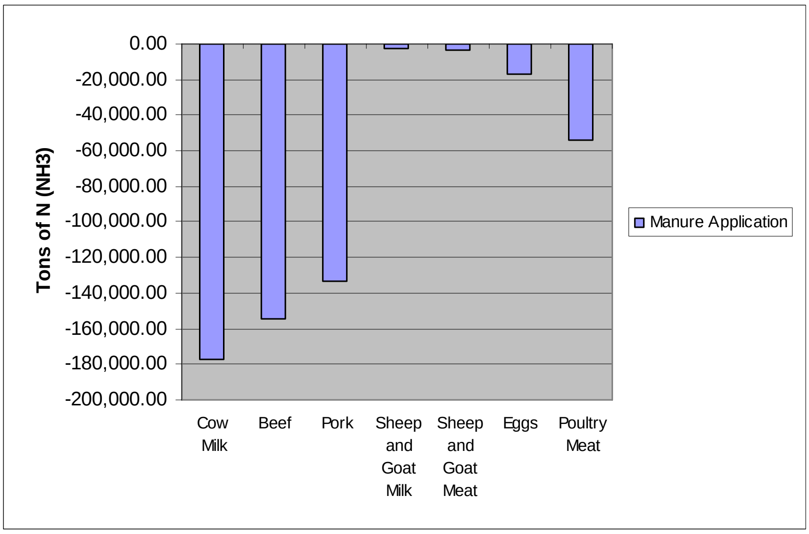

Figure 7.10: NH_3-Emission reduction potential for EU-27 for the scenario '100% Low ammonia application of manure (high efficiency)' in tons of N

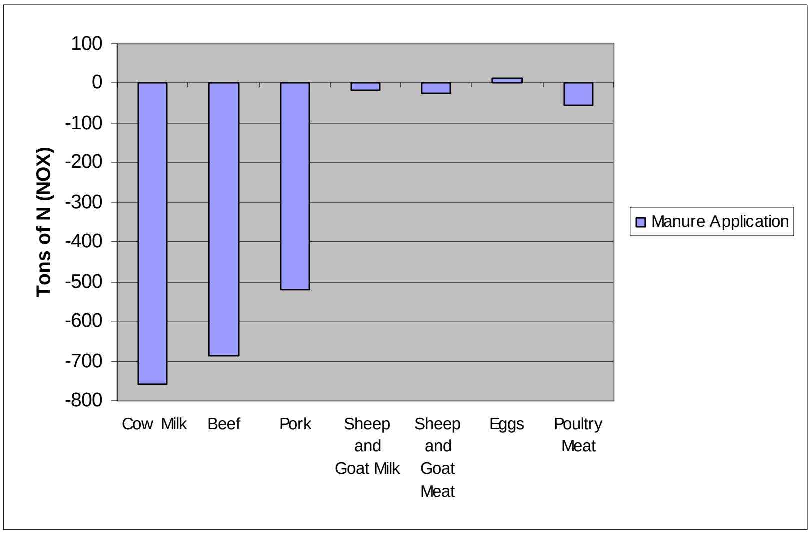

Figure 7.11: NO_X-Emission reduction potential for EU-27 for the scenario '100% Low ammonia application of manure (low to medium efficiency)' in tons of N

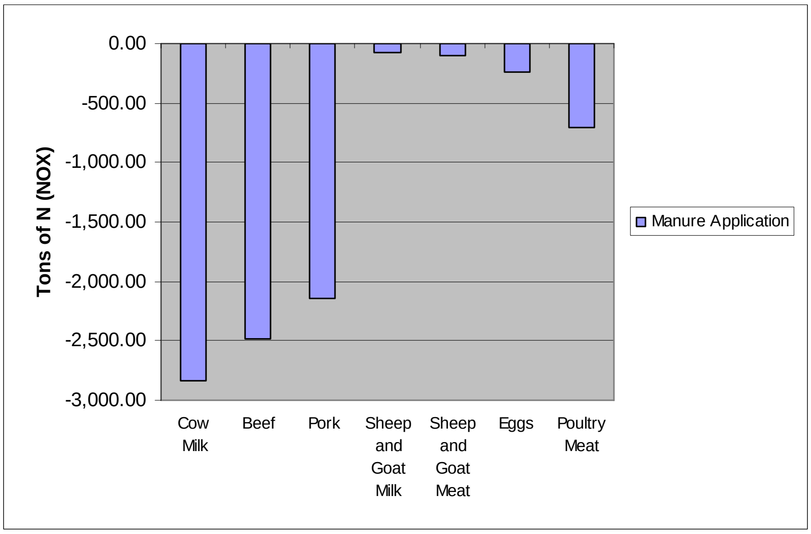

Figure 7.12: NO_X-Emission reduction potential for EU-27 for the scenario '100% Low ammonia application of manure (high efficiency)' in tons of N

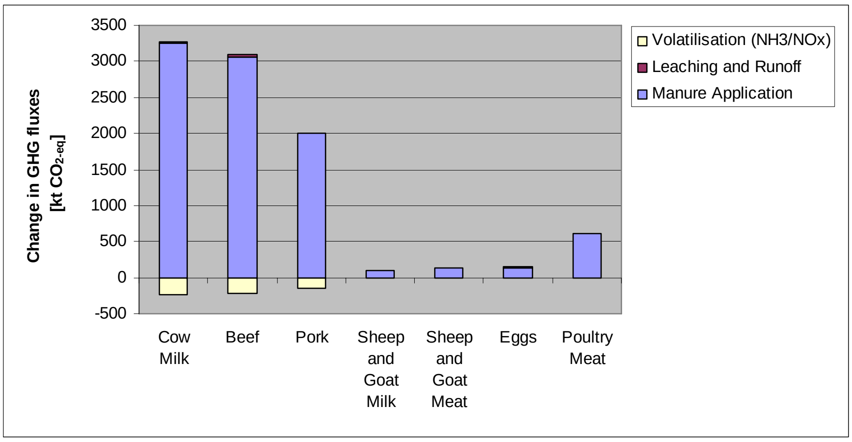

Figure 7.13: Effects on total GHG fluxes for EU-27 for the scenario '100% Low ammonia application of manure (low to medium efficiency)' in 1000 tons of $CO_{2\text{-}eq}$

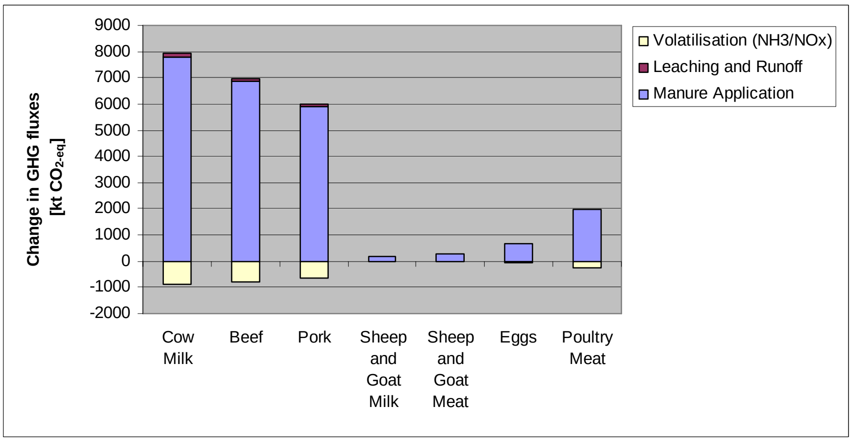

Figure 7.14: Effects on total GHG fluxes for EU-27 for the scenario '100% Low ammonia application of manure (high efficiency)' in 1000 tons of $CO_{2\text{-}eq}$

7.3.2.4 Urea substitution by ammonium nitrate for mineral fertilizer application

The share of N lost as ammonia is higher for urea than for other mineral fertilizers. Therefore, the substitution of urea with ammonium nitrate would reduce ammonia emissions. The respective GAINS loss factors are presented in section 4.2.4 (see also Klimont, 2004 and Velthof et al., 2007). The reduction of emissions from the application of mineral fertilizers affects EU livestock emissions via the use of feed. It has to be pointed out, that the emission reduction potential of urea substitution is supposed to be slightly underestimated here, since the emission factors for imported feed have not been adapted. Therefore, the values have to be interpreted in the sense that for each region only the domestic feed production is affected by the scenario, while all emissions from imported feeds (also those from other European regions) are equivalent to those in the base scenario II.

The substitution of urea by other mineral fertilizers would impact only on NH_3 emissions since the emission factor for NO_X is supposed to be equal for urea and other mineral fertilizers. Moreover,

there is a minor effect on N_2O and CO_2 emissions from the production of mineral fertilizers and volatilized NH_3. Therefore, NH_3 emissions of the EU livestock sector could be reduced by 52 thousand tons (-2%), total GHG fluxes by 551 thousand tons (-0.08%) of $CO_{2\text{-eq}}$ (see Figure 7.15 and Figure 7.16).

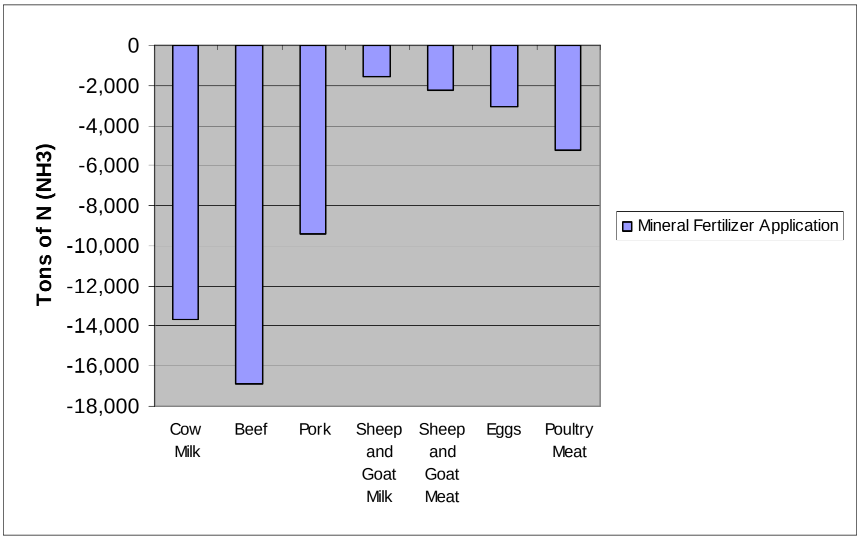

Figure 7.15: NH_3-Emission reduction potential for EU-27 for the scenario 'Urea Substitution' in tons of N

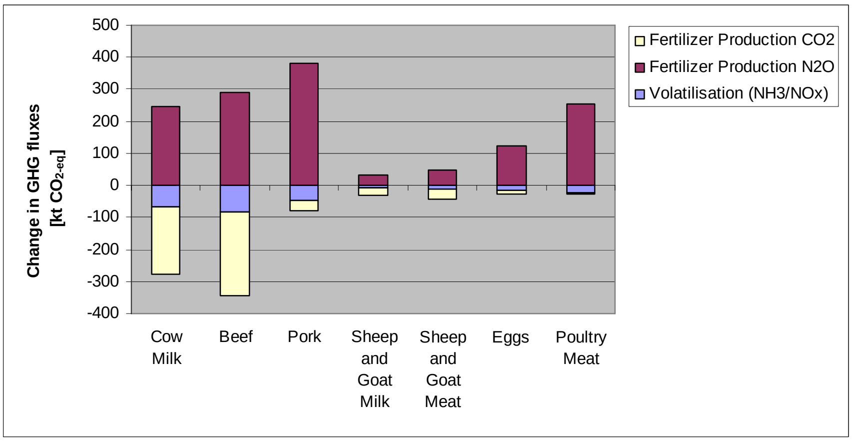

Figure 7.16: Effects on total GHG fluxes for EU-27 for the scenario 'Urea Substitution' in 1000 tons of $CO_{2\text{-eq}}$

7.3.2.5 No Grazing of Animals

It has been pointed out in section 7.2.1 that a reduction of the grazing intensity or the time animals spend on pastures would probably reduce GHG emissions due to lower emission factors and higher carbon sequestration rates. Therefore, we calculated the emissions of a scenario of zero percent grazing of animals. The respective emission factors for grazing and housing systems can be found in chapter 4. We considered effects on methane emissions (enteric fermentation and manure

management) and nitrogen emissions (N_2O, NH_3 and NO_X), but not CO_2 emissions from additional machinery use for grass cutting, storage and drying, which, however, is supposed to be less important. Moreover, since we use a simplistic approach for the quantification of carbon sequestration of grasslands, which uses a unique factor for all grassland, and statistics on the actual grazing intensity on European level are not available the effect of a reduced grazing intensity cannot be quantified with the CAPRI model. Finally, it was not assessed to which degree grass consumed by grazing animals could also be harvested at a reasonable cost, and which share would have to be replaced by feed crops. For this and other reasons (animal health etc.), the scenario should rather be considered as a pure thought experiment and by no means as a recommendation for this measure.

Surprisingly, the scenario leads to a slight net increase of total GHG fluxes by 5.4 Mio. tons (+0.8%) of $CO_{2\text{-eq}}$ in the EU-27, resulting in first line from beef and cow milk production (see Figure 7.17). According to the expectations, N_2O emissions from grazing went down, while N_2O-emissions from manure management and application went up. Due to a lower maximum methane producing capacity (see Table 4.2) of pasture compared to liquid and solid manure management systems also an increase of methane emissions from manure management is expectable, even if the higher net energy requirement for animal activity of grazing animals (see equations EF2 and EF6 in section 4.2.1 and equations MM1 and MM^2 in section 4.2.2) would impact in the opposite direction. Surprising is the increase in methane emissions from enteric fermentation, which was supposed to decrease due to the higher net energy requirement for animal activity of grazing animals. However, this decrease was overcompensated by a rise in emissions due to a lower digestibility of hay and silage compared to fresh grass directly taken up by grazing animals (see equation EF6 in section 4.2.1). The respective methodology for the calculation of the digestibility is presented in section 4.2.1. NH_3 emissions would increase by 555 thousand tons (+25%), NO_X emissions by 12 thousand tons (-18%) of N (see Figure 7.18 and Figure 7.19).

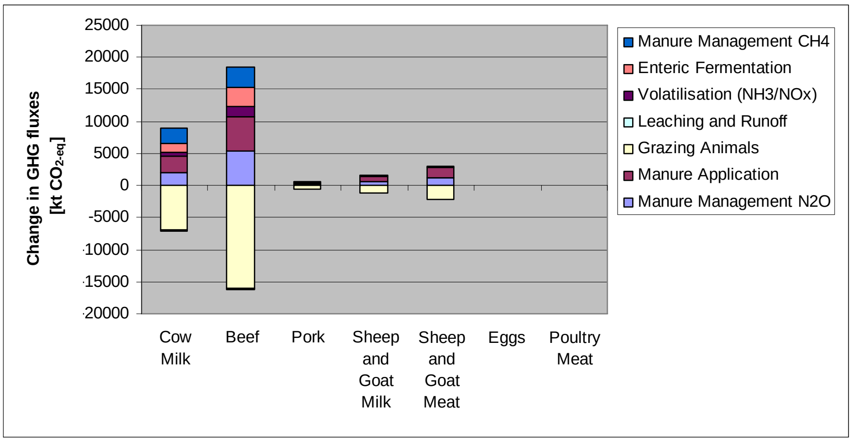

Figure 7.17: Effects on total GHG fluxes for EU-27 for the scenario 'No Grazing of animals' in 1000 tons of $CO_{2\text{-eq}}$

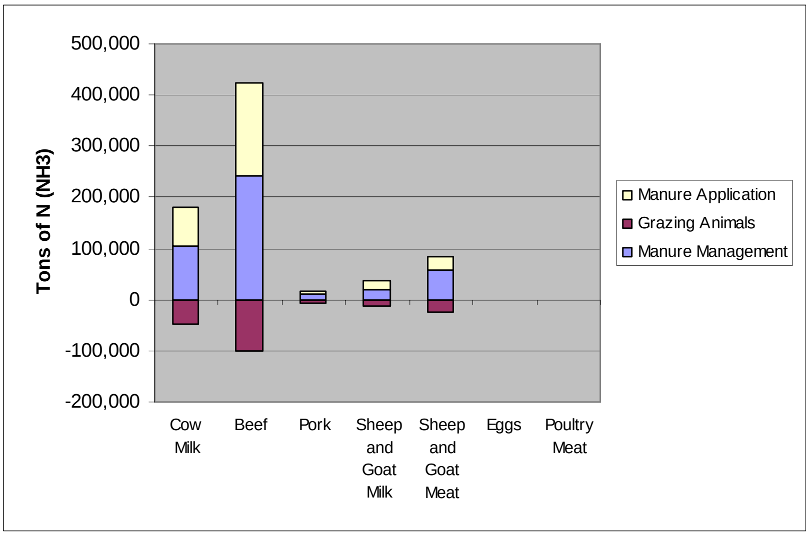

Figure 7.18:** NH_3-**Emission reduction potential for EU-27 for the scenario 'No Grazing of animals' in tons of N

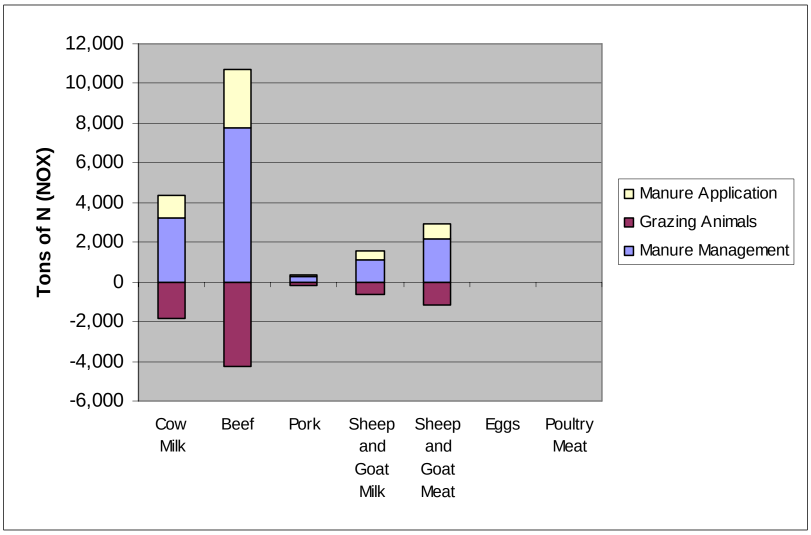

Figure 7.19:** NO_X-**Emission reduction potential for EU-27- scenario 'No Grazing of animals' in tons of N

7.3.2.6 Biogas production for animal herds of more than 100 LSU (livestock units)

Biogas production is supposed to be one of the most efficient ways to reduce greenhouse gas emissions, on the one hand by almost eliminating methane emissions from manure management and to a lower degree reducing N_2O emissions from the application of the digested slurry (see section 7.2), on the other hand by receiving carbon credits from the production of electricity or heat and, therefore, the reduction of emissions from the burning of fossil fuels. The reduction factors presented in section 7.2 (see Table 7.1) were only valid for liquid manure management systems, and, therefore, we assumed biogas produced only on the basis of slurry. In case of sheep, goats and poultry CAPRI does not differentiate liquid and solid systems, and so for those animal types we applied the factors generally. Since the installation of a biogas plant is a big investment a general

application would be very unrealistic. Therefore, we assumed a maximum implementation share equivalent to the national share of animals in farms above 100 LSU (livestock units). The data were taken from the farm structure survey 2007 and are presented in Table 7.2.

In those cases, where the national share of liquid manure management systems (see Table 4.6) was lower than the maximum implementation share, the share of liquid systems was supposed to increase to the respective level, impacting also on other emissions. Methane emissions from manure management were supposed to decline by 90% (see achieved.

), N_2O emissions from manure application to managed soils were reduced by 40% (see achieved.

), while for CO_2 credits we assumed the production of 450 m3 biogas per livestock unit, 1.85 kWh electricity per m3 biogas, and 0.54 kg of CO_2 saved per kWh. Technical data were taken from www.iwr.de/bio/biogas/Checkliste-Biogas-Anlage.html.

Table 7.2: National share of animals in farms with more than 100 live stock units (LSU)

	Dairy cows	Other cattle	Pigs	Sheep and Goats	Laying Hens	Other Poultry
Bulgaria	16%	21%	74%	10%	74%	94%
Belgium and Luxembourg	60%	62%	97%	27%	98%	98%
Greece	36%	29%	70%	4%	37%	77%
Spain	36%	51%	94%	40%	96%	91%
Austria	4%	4%	56%	2%	56%	81%
Romania	5%	9%	42%	9%	37%	72%
United Kingdom	89%	71%	95%	71%	94%	99%
Cyprus	69%	67%	94%	32%	78%	93%
France	50%	56%	96%	28%	95%	87%
Germany	55%	52%	87%	39%	91%	99%
Italy	53%	47%	93%	12%	96%	96%
Slovakia	94%	91%	91%	60%	98%	100%
Portugal	32%	53%	82%	21%	90%	75%
Ireland	57%	34%	100%	23%	92%	98%
Hungary	73%	69%	76%	26%	64%	96%
Finland	10%	20%	78%	4%	74%	98%
The Netherlands	64%	65%	97%	37%	99%	99%
Latvia	27%	27%	69%	1%	85%	100%
Slovenia	6%	5%	41%	0%	58%	74%
Czech Republic	93%	82%	95%	24%	98%	99%
Sweden	59%	39%	93%	17%	94%	100%
Estonia	77%	69%	96%	17%	88%	100%
Denmark	91%	63%	98%	28%	95%	100%
Malta	64%	60%	91%	9%	81%	69%
Lithuania	19%	25%	71%	15%	85%	91%
Poland	12%	16%	37%	11%	68%	88%

Source: http://epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/publications

The installation of biogas plants in all farms with more than 100 livestock units could reduce total GHG fluxes of EU-27 livestock production by 60 Mio tons (-9%) of $CO_{2\text{-eq}}$ (see Figure 7.20). Most of the reduction could be realized in beef (-14 Mio tons), cow milk (-12 Mio tons) and pork (-25 Mio tons) production. In terms of emission sources methane emissions from manure management could be reduced by 18 Mio tons of $CO_{2\text{-eq}}$, N_2O emissions from grazing animals by 14 Mio tons and the production of electricity could save 33 Mio tons of CO_2 emissions. Other N_2O-emissions would be affected only in a minor way, according to our calculations, and methane emissions from enteric fermentation would increase by 2 Mio tons, due to a reduction of grazing. In contrast to GHG emissions, NH_3 emissions would increase by 325 thousand tons (+15%) of N (see Figure 7.21) due to higher emissions from manure management and manure application. This is in first line

related to the assumed higher share of liquid systems and the lower share of grazing animals. Finally, NO_X emissions would increase by 86 thousand tons (+9%) of N.

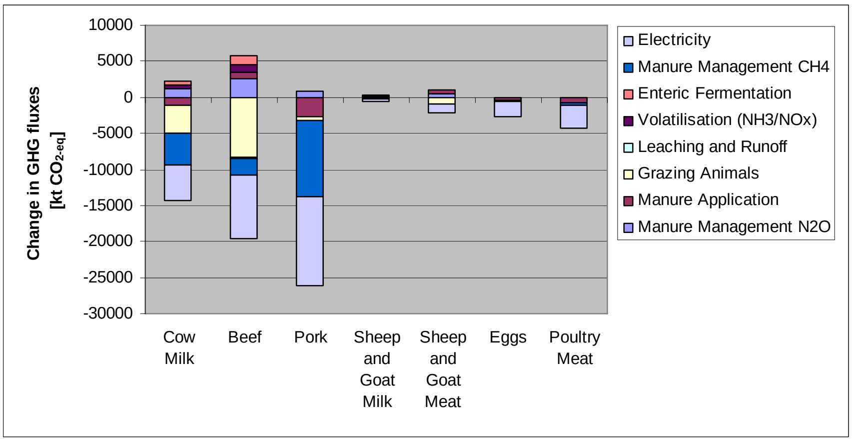

Figure 7.20: Effects on total GHG fluxes for EU-27 for the scenario 'Biogas' in 1000 tons of $CO_{2\text{-}eq}$

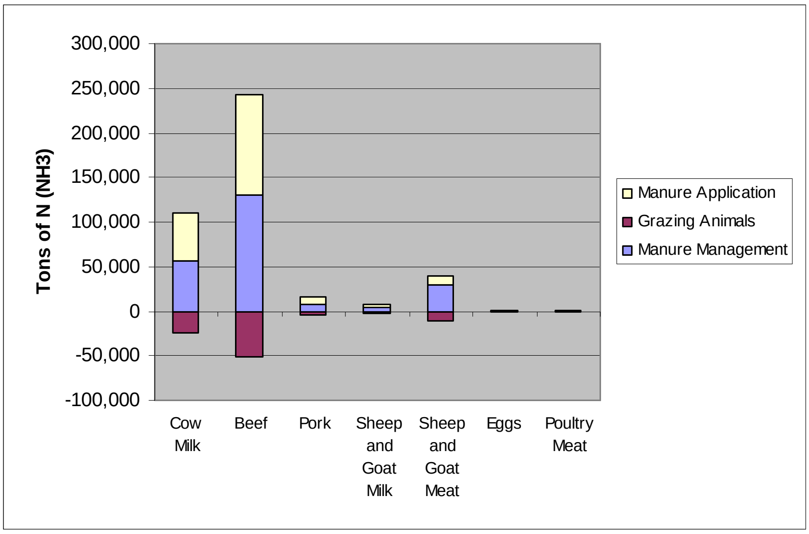

Figure 7.21: NH_3-Emission reduction potential for EU-27 for the scenario 'Biogas' in tons of N

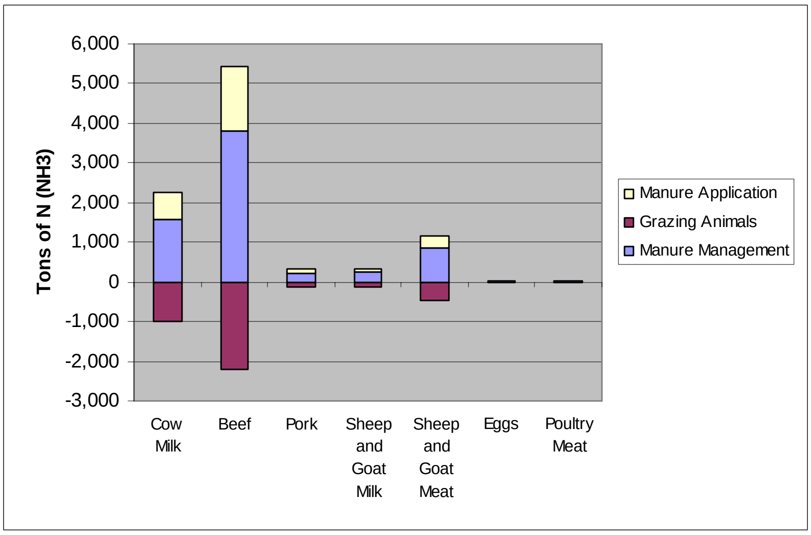

Figure 7.22: NO_X-Emission reduction potential for EU-27 for the scenario 'Biogas' in tons of N

8. PROSPECTIVE OVERVIEW OF EU LIVESTOCK EMISSIONS – AN EXPLORATORY APPROACH

Lead author: Ignacio Pérez Domínguez and Thomas Fellman; Contribution: Torbjörn Jansson (SLU, Sweden), Peter Witzke (EuroCare, Germany), Diti Oudendag (LEI, the Netherlands), Alexander Gocht (vTI, Germany)

8.1. Introduction

One of the objectives within the CAPRI-GGELS project is to assess the GHG and ammonia[7] 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 in respect of the following issues:

- In this task of the GGELS project 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.

- As the LCA approach is not operational for the policy scenarios a different model version has been used for the scenario exercises than for the quantification of GHG and ammonia emissions in the previous chapters. Therefore calculated emissions for the base year can be slightly different. Even though these differences do not substantially influence the projected scenario results, this has to be kept in mind when comparing the emission amounts of the two chapters.

- *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 EU27 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.

8.2. Definition of reference and mitigation policy scenarios

This sub-chapter deals with the building and definition of GHG mitigation policy scenarios and proceeds along the following structure. First, a brief overview of the proposed policy scenarios is given. Afterwards, for each single scenario a literature background, where appropriate, is given, and related variables and assumptions are described. The sub-chapter ends with an outline of limitations of the proposed approach.

[7] For the mitigation policy scenarios only methane and nitrous oxide emissions have been restricted. Ammonia is not a GHG, but is included in the list of gases analysed.

8.2.1. Scenario overview

Emission mitigation scenarios are constructed by selecting a restricted number of policy options, including regulatory tools and market based instruments for emission abatement. It has to be highlighted that the proposed and examined policy scenarios are meant to be exploratory, i.e. it is intended to explore what could happen if policies would be implemented that explicitly force farmers in the EU27 to reach certain GHG emission reduction targets. For this project three main sets of emission abatement scenarios are proposed: the implementation of emission standards, an emission tax and tradable emission permits. 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 (in CAPRI this is represented as the three-year average 2003-2005). The examined policy scenarios for a detailed analysis are (cf. Table 8.1):

- *Reference or Baseline Scenario (REF):* This scenario takes into account the most likely developments of agricultural markets, including the full implementation of the Health Check of the Common Agricultural Policy (CAP). The REF Scenario serves as comparison point in the year 2020 for counterfactual analysis of all other scenarios.
- *Emission Standard Scenario (STD):* This scenario is linked to an emission abatement standard homogenous across MS, with an equal emission 'cap' set on total GHG emissions in all Nuts 2 regions.
- *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 the EU effort sharing agreement.
- *Livestock Tax Scenario* (*LTAX*): This scenario tries to tackle emission reduction targets by introducing regionally homogenous taxes per cow and sheep.
- *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 all Nuts 2 regions. According to this 'cap' tradable emission permits will be issued to farmers and trade of emission permits will be allowed at regional and EU-wide level.

Table 8.1: Overview on policy scenarios in CAPRI-GGELS

Scenario acronym	Scenario Name	Policy Instrument	GHG abatement
REF	Reference Scenario	No specific policy measures implemented for GHG emission abatement in agriculture	Trend-driven
STD	Emission Standard Scenario	Emission standard with a regionally homogeneous cap (no trade in emission rights)	20% reduction in the year 2020 with respect to EU-27 emissions in the year 2004
ESAA	Effort Sharing Agreement for Agriculture	Emission standard with emission caps according to the EU effort sharing agreement (regionally differentiated caps, no trade in emission rights)	
LTAX	Livestock Tax Scenario	Emission tax on livestock (regionally homogenous taxes per cow and sheep)	
ETSA	Emission Trading Scheme for Agriculture	Tradable emission permits (regionally homogenous cap, with trade in emission rights at regional and EU-wide level)	

8.2.2. Reference scenario (REF)

The construction of a reference scenario (also called *baseline*) combines trends predicted by experts with trends as projected by statistical analysis (Britz and Witzke, 2008). Expert data on future trends are obtained from different sources doing forecasting research at EU level (Aglink and ESIM) and for non-EU regions and exogenous drivers (FAO and World Bank). This information and own trend projections using time series from the current CAPRI database are combined such that the most likely combination of a projected value subject to a larger set of consistency restrictions (e.g. closed area and market balances, feed requirements, production quotas, composition of cattle herds) is obtained.

The reference scenario can be interpreted as 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. The baseline assumes status-quo policy and includes future policy changes already agreed and scheduled in the current legislation, based on the information available at the end of June 2010. The changes in legislation proposed or adopted since that date have not been taken into account. Hence, the reference scenario incorporates a full implementation of the Health Check and the biofuels directive, as well as the sugar and milk market reform. However, although the agricultural sector is included in the GHG emission reduction obligation of the so-called climate and energy package of

2009, no explicit policy measures are considered for GHG emission abatement in the reference scenario[8].

Table 8.2: Summary of assumptions and scenario characteristics: reference scenario

GHG abatement policy	No specific policy measures implemented for GHG emission abatement in the agricultural sector
GHG abatement	Not explicit, i.e. linked to the development of agricultural markets (same feeding habits and emission factors)
Other features/ assumptions	The model allows for ex-post analysis of emissions through time (comparison of emissions in year 2020 with respect to a three-year average around 2004)

8.2.3. Emission Standard Scenario (STD)

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 methane emissions. CAC regulation commonly uses the setting of standards, i.e. a mandated level of performance that is enforced by law. As the name indicates, a CAC approach consists of a ‘command’ and a ‘control’ variable. Whereas the ‘command’ sets a standard or maximum level (‘cap’) of permissible pollution, the ‘control’ enforces and monitors the implementation of this standard. There are different types of standards that could be applied on agriculture in order to reduce GHG emissions[9], but due to technical restrictions related to the CAPRI model we have to focus in this project on emission standards that put a ‘cap’ on the level of GHG emissions. Restrictions on GHG emissions have not been directly implemented yet in EU agriculture, but indirectly through restrictions on rate of fertilizations within nitrates vulnerable zones (within the nitrate directive).

In this emission standard scenario a regionally homogenous ‘cap’ is set on GHG emissions from agriculture in the EU-27. The level of GHG emissions will be reduced by 20% in the year 2020 compared to emissions in the year 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 year 2020 on top of the legislation lined out in the reference scenario.

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[8] While MS actually have binding GHG emission abatement targets that also include agriculture, there are so far no explicit policy measures 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.
[9] Basically there are three types of standards: ambient standards, emission standards and technology standards.

Table 8.3: Summary of assumptions and scenario characteristics: emission standard scenario

Description	Emission standard with homogeneous emission restrictions in EU-27 regions and farming systems (emission 'cap' equally applied)
Year	2020
GHG abatement	20% reduction compared to a three-year average 2003-2005 Methane and nitrous oxide emissions covered (aggregated to CO2 equivalents by using IPCC global warming potentials)

8.2.4. *Effort Sharing Agreement for Agriculture Scenario (ESAA)*

This emission standard scenario describes a redistribution of a 20% GHG emission reduction commitment in EU-27 agriculture between the years 2005 and 2020 across MS following the so-called 'Effort Sharing Decision' (ESD) (c.f. Decision No 406/2009/EC, adopted jointly by the European Parliament and the Council). According to this agreement, the overall GHG emission reduction objective is distributed across MS, corresponding to a non-uniform GHG emission standard, i.e. while some MS (e.g. Germany) have to reduce GHG emissions by a certain level, other MS (e.g. Romania) are potentially allowed to even increase their emissions up to a defined level (see table below). This effort sharing mechanism was allowed by the KP to parties acting jointly such as the European Union.

Table 8.4: MS GHG emission limits in 2020 compared to 2005 emission levels according to the ESD

Member State	GHG emission limits		Member State	GHG emission limits
Belgium	-15		Luxembourg	-20
Bulgaria	20		Hungary	10
Czech Republic	9		Malta	5
Denmark	-20		Netherlands	-16
Germany	-14		Austria	-16
Estonia	11		Poland	14
Ireland	-20		Portugal	1
Greece	-4		Romania	19
Spain	-10		Slovenia	4
France	-14		Slovakia	13
Italy	-13		Finland	-16
Cyprus	-5		Sweden	-17
Latvia	17		United Kingdom	-16
Lithuania	15			

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.

For the ESAA scenario the distribution key of the effort sharing decision is taken as starting point for an uneven distribution of GHG emission limits at MS level. These MS limits are applied to

agricultural emissions according to a linear modification, such that 20% GHG emission can be achieved in the EU-27 (the exact distribution is given in the respective chapter of the scenario).

It has to be further noted, that this ESAA 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 20% emission reduction in the EU-27 against the base year in CAPRI (three year average 2003-2005). The rationale behind this scenario is to model an uneven distribution of MS targets; however it is clear that any such new distribution key would be an ultimately political decision. So 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. Here, as in the emission standard scenario, all agricultural CO_2 equivalent emissions are taken into account. These targets are defined at the MS level and homogeneously applied to all regional production systems within the respective MS. Therefore, all agricultural producers in a given MS would be given emission quotas above or below their current level (as specified in the table) without the ability to exchange them.

Table 8.5: Summary of assumptions and scenario characteristics: effort sharing agreement for agriculture

Description	Emission standard with heterogeneous emission restrictions in EU-27 regions and farming systems (emission 'caps' according to a specific effort sharing agreement for agriculture)
Year	2020
GHG abatement	20% reduction compared to a three-year average 2003-2005 Methane and nitrous oxide emissions covered (aggregated to CO2 equivalents by using IPCC global warming potentials)

8.2.5. Livestock Emission Tax Scenario (LTAX)

Livestock emit considerable amounts of greenhouse gases. Whereas direct emissions from livestock come from the respiratory process in form of carbon dioxide, ruminants in particular emit methane as part of their specific digestive process. In order to reduce the contribution of ruminants on GHGs, one possibility would be to directly reduce emissions by capping animal herd sizes or enforcing new technologies. Another possibility would be to indirectly affect livestock emissions through the implementation of livestock taxes. Although such a livestock tax is not yet implemented in any MS of the EU, press reports indicate that it has been recently taken into consideration bin Ireland. The Irish Times reported suggestions to impose a tax set at 5€ per tonne of CO_2 emitted per ruminant (which should generate revenue worth 104€ million for the Irish Government). Converted into a tax per ruminant livestock head, such a livestock emission tax would imply an annual levy of 13€ per dairy cow (0.27€ cent per kg[10]), 7€ per non dairy cow and 1€ per sheep (Irish Times, 2009). Similar to the Irish approach, other countries like Denmark and the USA also have considered the implementation of a livestock tax. The Danish tax commission

[10] Assumed production of 5.000 kg per cow.

recommended that a cow tax should be imposed and suggested an amount as high as €80 per animal, however this levy proposal did not went through the Danish parliament.

It is not clear whether the rates of levy on livestock as proposed in Ireland or Denmark would have significant impacts on production of milk and meat and, therefore, reduce GHG emissions. Furthermore, no formal initiatives have been taken up to now to implement a livestock tax within the EU. Nevertheless, and as the literature does not provide information or case studies about possible effects, it can be considered as a reasonable exploratory approach to analyse the effects of a possible implementation of a livestock tax.

For this exploratory exercise the livestock tax will be set at an amount so that a GHG emission reduction of 20% will be met in the year 2020 in the EU-27 (as in the other simulation scenarios). Therefore we modelled the effect of an EU-wide livestock tax of 300€ per ton of CO_2 equivalent emissions from ruminants and 160€ for non-ruminants, including not only CH_4 but also N_2O from manure management activities[11]. The tax is split across the livestock types according to their emission intensities. It has to be noted, that in this study the generated revenues from the livestock tax system would not revert into the system[12].

Table 8.6: Summary of assumptions and scenario characteristics of the livestock tax scenario

Description	Carbon tax on livestock activities in the EU-27 (differentiating ruminants and non-ruminants)
Year	2020
GHG abatement	20% reduction compared to a three-year average 2003-2005, only determined through taxing livestock activities Methane and nitrous oxide emissions covered (aggregated to CO2 equivalents by using IPCC global warming potentials)
Carbon tax	300 Euro per ton of CO2 for ruminants and 161 Euro per ton of CO2 for non-ruminants: - "prohibitive" tax in order to achieve the overall emission reduction (for comparability with other scenarios) - taxing of emissions from ruminants 53% higher than from non-ruminants (Irish Times (2009))

8.2.6. Tradable Emission Permits Scenario (ETSA)

8.2.6.1 Emission trading systems in general

In an Emission Trading System (ETS) GHG emissions of all participants are limited and target amounts (‘caps’) are decided on, usually amounting to less emission than encountered at present (depending on the agreed emission target that in rare cases also allows increase in emission). According to the allocation procedure participants are assigned a certain amount of emission rights for a trading period that then can be made use of. The initial distribution of the emission permits can be done in different ways: a) free distribution according to historical emission rates (so-called ‘grandfathering’), b) equal distribution among all emitters, c) auctioning to the highest bidder, or d) combined systems (e.g. all emitters receive a basic volume of emission permits and the reminder of the permits is auctioned). However, in a well functioning emission permits market the way the

[11] Emissions from manure management are included in the system. The calculations in CAPRI are performed at IPCC Tier 2 level, so that nutrient intake and excretion by animals, as well as intensity, is considered in the simulation.
[12] In practice the tax revenue raised could for example be used to pay for emission reduction efforts in the agricultural or other sectors.

initial rights are allocated affects only the initial distribution but should not affect the final distribution after emission permits are traded[13].

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. Applying to a list of energy and industrial production activities and covering all GHG included in Annex A of the Kyoto Protocol (KP), the legislation aims at reductions of GHG emissions in a cost-effective and economically efficient manner (article 1 of the KP). However, only CO_2 emissions are effectively covered by the directive according to the categories of polluting activities defined in Annex 1. Whereas trading is first applied only to industrial and energy-producing activities, other sectors might be included in the future with a view to further improving the economic efficiency of the scheme[14] through possible amendments (article 30). This is an important point with regard to the potential extension of an ETS to the agricultural sector.

The possible inclusion of agriculture in an existing ETS or alternatively the implementation of an ETS explicitly for the agricultural sector is an issue that is already controversially discussed in several countries. Sadler et al. (2008) highlight the current debate in Australia and stress the need to include incentives to adopt best-practice methods of emission abatement in the agricultural sector, without effectively taxing production through any rigid emission abatement mechanism. The Australian Government is expected to take a decision on the inclusion of agriculture in its Carbon Pollution Reduction Scheme in 2013, which would raise the coverage of Australian emissions from 75% to 90%. $Lenno_x$ et al. (2008) and Kerr et al. (2008) describe the main characteristics of the New Zealand ETS, where agriculture is foreseen to be included in a 'cap and trade' scheme by January 2013, covering then 90% of total GHG emissions. Breen (2008) outlines the importance of targeting GHG emission from agriculture in Australia and New Zealand, countries where this sector shows considerably larger emissions shares (i.e. 16% and 48% in 2006 respectively) than in the EU (10% in 2006). On these grounds, Breen (2008) also discusses the introduction of Irish agriculture in an ETS, since methane and nitrous oxide emissions represent 25% of total Irish GHG emissions. Radov et al. (2007) analyse the scope and feasibility of an ETS for the UK, but do not include a quantitative assessment of its relative merits compared to other regulatory approaches.

8.2.6.2 Scenario description

This tradable emission permits scenario assumes the explicit implementation of an Emission Trading Scheme for Agriculture (ETSA) in the EU-27.[15] The ETSA is meant to implement an European market of agricultural GHG emission permits affecting all agricultural production activities (i.e. livestock and crop activities are both included in this ETSA, due to the life cycle approach taken). With this purpose, information on transaction costs (TC)[16] related to existing emission trading schemes is explicitly considered, since TC are expected to have an important effect on the economic performance of such a policy instrument as tradable permits.

[13] Nonetheless it has to be noted that the initial distribution has an effect on income and wealth implications for participants.
[14] The list of activities included in annex I of the directive might be subject to future revision.
[15] In this hypothetical scenario, the inclusion of the livestock sector in the ETSA would then require its exclusion from the ESD.
[16] 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 modelling exercise the target is to achieve a 20% GHG emission reduction in the year 2020 compared to EU-27 emissions in a three-year average 2003-2005 (i.e. base year in the CAPRI model). Therefore a regionally homogeneous emission 'cap' is set on total GHG emissions in all Nuts 2 regions. According to this 'cap' and historical emission levels the emission permits are allocated to agricultural producers (1 permit equals 1 ton of $CO_{2\text{-eq}}$, where CH_4 and N_2O emissions from agricultural sources are considered). While 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), MS and EU-27 wide level. Hence, 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.

Variable and fix transaction costs (TC) are introduced, both with the effect of increasing marginal abatement costs (MAC). Variable TC are mainly brokerage fees and are paid by permit buyers. In the scenario 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 will be carried out with the model. Moreover, institutional costs of the trading scheme (approximately 50 Million Euro) are proposed as fix costs for setting up and maintaining the emission trading market. These fix costs are also assumed to be paid by permit buyers and therefore distributed over transactions. TC are defined based on information found in the literature for Clean Development Mechanism (CDM) and Joint Implementation (JI) projects in different economic sectors and size of the markets (compilation by Eckermann et al. 2003, pp. 6-8).

Table 8.7: Summary of assumptions and scenario characteristics: tradable emission permits scenario

Description	Emission trading scheme for the agricultural sector, with EU-27 wide trade of emission permits (1 permit = 1 ton of CO2 equivalent)
Year	2020
GHG abatement	20% reduction compared to a three-year average 2003-2005 Methane and nitrous oxide emissions covered (aggregated to CO2 equivalents by using IPCC global warming potentials)
Transaction costs	Variable: 5€ per permit transaction Fix: 10MM€ (2 MM € per year to amortize in 5 years)

8.2.7. Limitations of the scenario exercise

Several issues that are not covered in the current analysis are worth mentioning. Firstly, emission abatement in CAPRI is related strictly to agricultural direct emissions[17] and does neither cover indirect emissions, like e.g. related to fertilizer production, nor emissions from other pollutants, like e.g. SO_2, nor changing carbon sequestration resulting from changes in land management techniques and introduction of alternative crop rotations (as in Lal, 2004; Reilly et al. 2007, p.178). Secondly, due to the restriction to agriculture, changes in the forestry or energy sectors resulting from

[17] As included in paragraph 4 of the official reporting to the United Nations Framework Convention on Climate Change (UNFCCC) by MS.

adjustment in agricultural production are not considered (as in Böhringer, 2000, p.780; Truong et al., 2007). Moreover, agricultural processing activities for explicit mitigation of GHG emissions, e.g. biofuel or biogas production (Gielen et al. 2003, pp.179-180; Pathak et al. 2009, p.408) are subject to further research. The analysis, hence, builds up on a simplified emission accounting scheme and not on on-farm measurements of emissions or more elaborated emission coefficients depending on single processes as in Moran (2009). Finally, it should be mentioned, that currently technological responses to policy measures, like the adaptation of stables or livestock keeping methods, can not be considered in the CAPRI model. Therefore, the system responds only in form of price and production quantity changes.

8.3. Emission projections for the year 2020

8.3.1. Introduction

In this chapter the reference scenario (REF) is presented and the results regarding agricultural market developments and emission projections for the year 2020 are briefly analysed. The reference scenario (also called *baseline*) takes into account the most likely developments of the European agricultural sector under the status-quo policy, including the full implementation of the Health Check of the CAP. The reference scenario will serve as comparison point in the year 2020 for counterfactual analysis of the proposed mitigation policy scenarios. It has to be kept in mind that the reference scenario as presented here should not be interpreted as a forecast of what the future will be, but as a description of what may happen under a specific set of assumptions, which at the time when the projections are made were judged plausible.

The construction of the CAPRI baseline basically requires two major steps. The *first step* of the CAPRI baseline process mainly relies on an analysis of historical trends and on expert information for particular issues. The most important expert information was the AGLINK baseline availabe when this analysis was conducted. This AGLINK baseline includes recent assumptions on macroeconomic drivers (GDP, population, oil price) and the evolution of the CAP, in particular the expiry of the milk quota system that is expected to have an influence on the cattle population and therefore on CH_4 emissions.

However, the regional resolution of the AGLINK baseline in the EU is limited to EU15 and the new Member States (NMS = EU12). Therefore our CAPRI baseline also includes national expert information on several MS, where this was available in time and in a usable quantitative format. Furthermore this baseline includes specific expert information from the PRIMES energy model for the biofuel sector and expert projections from the seed manufacturer KWS on the sugar sector.

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, but possible, if needed for a technically consistent quantity framework that also includes price projections.

The *second step* of the CAPRI baseline process supplements the consistent price-quantity framework with a detailed policy specification, in particular:

- Direct payment regime updated to reflect further decoupling under the CAP Health Check agreement;
- Abolition of mandatory set-aside;
- Phasing out milk quotas;
- Intervention mechanism reduced to wheat, butter and skimmed milk powder;
- Further market reforms already agreed on (like for sugar), but
- No Doha agreement (i.e. EU agricultural trade policy remains in conformity with the Uruguay Round Agreement on Agriculture, URAA) and no assumptions are made concerning bilateral trade agreements currently under negotiation.

These 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 2020 are more crucially determined by step one, the baseline process and thus from the integration of trends, expert information, and technical constraints.

8.3.2. Reference scenario results

This chapter provides a description and brief analysis of the reference scenario results. First, the projection of agricultural market developments between 2004[18] and 2020 is presented, followed by the projection of the development of agricultural emission inventories in the same period. In the subsequent subchapters, the results of the reference scenario are then contrasted with the results of the policy mitigation scenarios in order to provide a measure of the impact of the emission abatement policies analysed.

8.3.2.1 Projection of agricultural markets between 2004 and 2020

In this section the projected developments of agricultural markets between 2004 and 2020 are presented. In addition to looking 16 years ahead from the base year 2004 (three year average 2003-2005) to year 2020 the following tables include for selected variables also a comparison with the situation in 1991, to put the changes in some perspective. The year 1991 is chosen because it is the first year in the CAPRI database with fairly settled data for Germany after reunification and it immediately precedes the MacSharry reform of the CAP.

[18] Once again it has to be noted that the base year in the CAPRI system is a three year average around 2004 (i.e. the base year 2004 represents the 2003-2005 average).

Table 8.8: Dairy sector development by EU MS, base year compared to the baseline year 2020

	Base year (BAS, 2004)						Baseline (REF, 2020)		
	Dairy herd [1000 hd]	Yield [1000 t]	Production [1000 t]	*Dairy herd [% to 1991]*	*Yield [% to 1991]*	*Production [% to 1991]*	*Dairy herd [% to BAS]*	*Yield [% to BAS]*	*Production [% to BAS]*
Austria	552	5197	2869	-37%	75%	10%	-10%	23%	11%
Belgium-Lux.	611	5311	3243	-29%	32%	-6%	2%	9%	11%
Denmark	579	7781	4507	-23%	28%	-1%	-14%	14%	-2%
Finland	327	7354	2404	-25%	29%	-4%	-26%	15%	-15%
France	3938	6010	23670	-22%	25%	-2%	-14%	15%	-1%
Germany	4312	6410	27642	-28%	39%	1%	-15%	22%	3%
Greece	151	4773	722	-29%	55%	10%	-10%	18%	7%
Ireland	1140	4641	5290	-11%	13%	0%	0%	8%	8%
Italy	2034	5397	10978	-22%	39%	8%	-7%	16%	8%
Netherlands	1517	7063	10717	-20%	25%	0%	8%	4%	13%
Portugal	327	6006	1966	-14%	43%	23%	-19%	16%	-6%
Spain	1105	5706	6308	-28%	42%	3%	-10%	17%	5%
Sweden	401	7934	3179	-25%	31%	-1%	-15%	16%	-1%
United Kingdom	2109	6840	14423	-25%	31%	-2%	-16%	13%	-4%
EU15	19104	86422	117917	-24%	34%	1%	-10%	15%	3%
Cyprus	26	5282	137	14%	41%	60%	-11%	10%	-3%
Czech Republic	415	6298	2611	-55%	46%	-34%	-47%	33%	-30%
Estonia	112	5032	564	-59%	41%	-42%	-41%	22%	-28%
Hungary	291	6123	1785	-41%	41%	-17%	-32%	16%	-22%
Latvia	170	3591	612	-68%	19%	-62%	-22%	3%	-20%
Lithuania	424	3413	1448	-49%	12%	-43%	-23%	20%	-7%
Malta	6	5936	38	11%	-2%	9%	29%	29%	66%
Poland	2577	4170	10747	-42%	57%	-8%	-38%	27%	-21%
Slovac Republic	156	5752	896	-51%	31%	-35%	-36%	19%	-24%
Slovenia	130	4210	545	-15%	26%	8%	-22%	16%	-10%
10 New MS	4308	49807	19384	-46%	30%	-22%	-35%	20%	-21%
Bulgaria	363	3479	1263	-39%	15%	-30%	-13%	-7%	-19%
Romania	1489	3367	5013	-15%	26%	7%	-15%	-4%	-19%
Bulgaria/Romania	1852	6846	6276	-21%	20%	-3%	-15%	-6%	-19%
EU27	25264	143075	143577	-29%	32%	-3%	-15%	16%	-1%

The milk quota regime historically limited the production changes in EU15 countries to small percentage changes, i.e. the milk production was nearly constant at the EU15 level. Some exceptional quota increases in Greece, Italy and Portugal permitted a stronger growth in production which also led to a more complete filling of quotas in Portugal. Austria developed to a systematic overproducer in the historical period. The quota regime imposed a continuous decline of dairy herds in the past to comply with increasing yields, in particular where yield growth has been very strong (e.g. Austria). Projection results for the year 2020 indicate, that the removal of the quota constraint as of 2015 is likely to lead to a slight milk production increase in EU15 (+3%), with growing dairy herd sizes only in the Netherlands (+8%) and Belgium-Luxembourg (+2%). All other EU15 MS (except Ireland) see a decline in dairy herd size, most likely following the pressure form declining prices on the one hand and increases in milk yields on the other hand (most pronounced in Finland, UK, Portugal). But even in competitive regions like Austria continuous yield growth may be so strong that dairy herds decline in spite of an increase in production.

The EU12 countries have made the transition from a centrally planned system to the market system, which involved a strong drop in production in most countries except Slovenia and Romania and yield growth lagging behind the progress in EU15 countries. The baseline indicates that yield growth in the EU12 will be stronger than in the EU15, given that they are further away from the technical frontier and intra EU technology transfer is rather easy, except for Bulgaria and Romania where restructuring is expected to imply stagnating yields. Nonetheless this baseline assumes, in

line with many special studies on dairy markets, that EU12 countries will loose market shares and that their production and dairy herds are likely to decline.

Table 8.9: Beef sector development by EU MS, base year compared to the baseline year 2020

	Base year (2004)						Reference year (2020)			
	Beef* herd [1000 hd]	Production [1000 t]	Demand [1000 t]	Net trade [1000 t]	*Production [% to 1991]*	*Demand [% to 1991]*	*Beef* herd [% to BAS]*	*Production [% to BAS]*	*Demand [% to BAS]*	Net trade [Δ to BAS]
Austria	661	213	149	64	-18%	-18%	-18%	-15%	-15%	-10
Belgium-Lux.	810	310	187	122	-22%	-19%	-14%	-9%	2%	-32
Denmark	432	142	148	-6	-33%	21%	-21%	-21%	44%	-95
Finland	238	92	95	-3	-24%	-7%	-2%	-16%	-1%	-14
France	6674	1831	1582	249	-10%	-13%	-4%	-7%	2%	-172
Germany	3088	1298	1021	277	-43%	-35%	-45%	-26%	-45%	113
Greece	290	50	180	-130	-24%	-11%	9%	-8%	-21%	34
Ireland	2651	570	48	523	-2%	-69%	-2%	8%	81%	6
Italy	2696	970	1429	-459	8%	-5%	-9%	-4%	-10%	114
Netherlands	160	376	334	43	-34%	1%	-61%	-11%	11%	-78
Portugal	621	117	194	-77	-6%	16%	3%	9%	3%	5
Spain	4162	680	640	40	35%	27%	8%	7%	25%	-114
Sweden	450	141	205	-64	-5%	29%	-22%	-11%	31%	-79
United Kingdom	3895	847	1197	-350	-17%	0%	-9%	-4%	14%	-209
EU15	26829	7637	7409	228	-17%	-10%	-9%	-8%	-1%	-532
Cyprus	11	4	6	-2	-10%	-33%	56%	21%	4%	1
Czech Republic	292	100	93	8	-65%	-67%	-58%	-39%	-74%	29
Estonia	49	18	15	4	-67%	-70%	-49%	-36%	-76%	4
Hungary	90	45	37	8	-67%	-56%	-48%	-29%	-23%	-4
Latvia	61	20	22	-2	-85%	-83%	3%	0%	-2%	0
Lithuania	150	51	40	11	-70%	-69%	-62%	-36%	-63%	7
Malta	3	1	11	-10	28%	-29%	19%	24%	-13%	2
Poland	818	361	287	74	-38%	-51%	5%	1%	-25%	74
Slovac Republic	68	41	41	-1	-57%	-56%	-48%	-25%	-50%	10
Slovenia	138	55	58	-4	56%	61%	-11%	-7%	6%	-7
10 New MS	1680	696	609	87	-53%	-57%	-20%	-12%	-33%	116
Bulgaria	125	46	73	-27	-60%	-33%	80%	26%	-7%	17
Romania	977	233	228	5	-36%	-36%	5%	-7%	-6%	-2
Bulgaria/Romania	1102	279	301	-21	-42%	-35%	14%	-1%	-6%	15
EU27	29612	8613	8318	294	-23%	-18%	-9%	-8%	-4%	-401

* 'Beef herd' = suckler cows + adult cattle for fattening in this table.

Production of beef has been declining in EU15 countries by 17% since 1991 and this decline is projected to continue at somewhat reduced pace (-9% in 2020). It should be noted that this decline is not due to the earlier mentioned decline in the dairy herds as this link is weakened by the possibility to replace dairy cows with suckler cows and by the possibility to adjust the slaughtering of calves as opposed to adult cattle. Thus we had the strongest beef production decline in the past in Germany (-43%) and the strongest increase in Spain (+35%) and yet the dairy herds in both countries declined by the same amount (-28%, a bit more that the EU15 average). The projected changes may be seen to be related to past developments, but with some levelling off, such that the strong changes in Germany and Spain, for example, are continuing in direction, but with a moderated speed. The evolution of non-dairy adult cattle is clearly related to beef production, but in countries like the Netherlands, where the suckler cow herd is very small relative to the dairy herd, we may also have a very strong decline of the beef herd that competes for fodder with the expanding dairy herd which in turn limits the decline of beef production.

Demand side developments in EU15 are at least as diverse as supply side changes. Thus we have strongly increasing demand trends like in Denmark alongside with strongly declining trends of beef consumption as in Germany, that are projected to continue. Both in Ireland and in the UK a strong decline in demand could be observed up to 1996 and then a recovery, with increasing demand projected to continue in these countries.

In EU12 we see that the restructuring difficulties in the livestock sector are expected to contribute to a further decline of production and the beef herd, but with clear signs of a stabilisation in important producer countries like Poland. Demand developments are fairly heterogeneous as in the past, but on average the future drop in demand is expected to exceed the decline on the supply side, contrary to EU15. However, as the economic weight of EU15 is dominating in EU-27, an increase in EU-27 net imports of about 0.4 million tons is projected.

Table 8.10: Sheep sector development by EU MS, base year compared to the baseline year 2020

	Base year (2004)						Reference year (2020)			
	Ewes & goats [1000 hd]	Production [1000 t]	Demand [1000 t]	Net trade [1000 t]	*Production [% to 1991]*	*Demand [% to 1991]*	*Ewes & goats [% to BAS]*	*Production [% to BAS]*	*Demand [% to BAS]*	Net trade [Δ to BAS]
Austria	290	7	9	-2	*48%*	*21%*	*6%*	*6%*	*-1%*	1
Belgium-Lux.	140	3	24	-21	*-42%*	*7%*	*-5%*	*-9%*	*-4%*	1
Denmark	78	2	7	-5	*-12%*	*42%*	*5%*	*0%*	*15%*	-1
Finland	53	1	2	-1	*-47%*	*14%*	*11%*	*12%*	*23%*	0
France	7805	133	268	-135	*-21%*	*-16%*	*-14%*	*-22%*	*-10%*	-3
Germany	1851	46	84	-39	*7%*	*14%*	*1%*	*9%*	*-4%*	8
Greece	10640	115	135	-20	*-7%*	*-5%*	*-4%*	*-12%*	*-2%*	-11
Ireland	3425	69	19	50	*-27%*	*-33%*	*-27%*	*-30%*	*-2%*	-21
Italy	7466	23	88	-65	*-58%*	*-18%*	*2%*	*8%*	*-16%*	16
Netherlands	1153	22	19	3	*-28%*	*27%*	*20%*	*9%*	*37%*	-5
Portugal	2325	24	33	-9	*-22%*	*-21%*	*-11%*	*-27%*	*-15%*	-1
Spain	19541	246	229	16	*4%*	*-11%*	*-8%*	*-17%*	*-8%*	-23
Sweden	191	4	10	-5	*4%*	*86%*	*0%*	*-7%*	*12%*	-1
United Kingdom	15889	329	361	-33	*-23%*	*-17%*	*-7%*	*-10%*	*2%*	-40
EU15	70847	1023	1288	-264	*-17%*	*-12%*	*-7%*	*-14%*	*-5%*	-81
Cyprus	440	8	9	-1	*19%*	*19%*	*41%*	*-20%*	*39%*	-5
Czech Republic	86	4	0	4	*-63%*	*-95%*	*-46%*	*-26%*	*-100%*	-1
Estonia	30	0	0	0	*-80%*	*-82%*	*-24%*	*-8%*	*106%*	0
Hungary	1054	10	4	6	*-22%*	*-34%*	*-4%*	*-18%*	*164%*	-8
Latvia	29	1	1	0	*-86%*	*-85%*	*0%*	*-7%*	*44%*	0
Lithuania	34	1	2	-1	*-37%*	*55%*	*-28%*	*-12%*	*41%*	-1
Malta	8	0	1	-1	*9%*	*-41%*	*63%*	*-1%*	*-84%*	1
Poland	304	5	2	2	*-92%*	*-94%*	*-24%*	*-10%*	*38%*	-1
Slovac Republic	260	3	3	0	*-53%*	*-50%*	*-18%*	*-8%*	*79%*	-3
Slovenia	80	0	0	0	*107%*	*80%*	*98%*	*19%*	*32%*	0
10 New MS	2326	33	24	10	*-68%*	*-68%*	*2%*	*-16%*	*60%*	-20
Bulgaria	2333	65	52	13	*-28%*	*-28%*	*-37%*	*-19%*	*91%*	-60
Romania	6653	79	55	24	*-21%*	*-43%*	*35%*	*8%*	*-9%*	12
Bulgaria/Romania	8986	144	107	38	*-24%*	*-36%*	*16%*	*-4%*	*40%*	-48
EU27	82160	1201	1418	-217	*-21%*	*-17%*	*-4%*	*-13%*	*0%*	-149

The sheep sector is next important to cattle for CH_4 emissions, but with a much lower weight. The key producers in EU15, France, Greece, Spain and the UK are projected to see a decline in production. This development would be a revision of the past growth in the case of Spain, based on national expert information. For the largest producer UK we expect a stabilisation at moderately reduced level such that the past decline in production and in the sheep herd of EU15 would be moderated. For the largest producer in the EU12 group it also appears that the strong drop in production has come to an end. Expected demand developments on the large markets mostly

resemble the past evolution except for the UK where it appears that the past decline in demand is levelling off. The evolution in EU12 countries may be seen to be very diverse and often showing large changes. It should be recognised, however that markets in EU12 are very small, with the whole of EU10 demand equal to that of Belgium-Luxembourg in the base year. Large percentage changes are possible when the initial level is low. In general EU-27 demand is declining less than supply such that net imports would have to increase.

Table 8.11: Pig sector development by EU MS, base year compared to the baseline year 2020

	Base year (2004)						Reference year (2020)			
	Fattened pigs [1000 hd]	Production [1000 t]	Demand [1000 t]	Net trade [1000 t]	*Production [% to 1991]*	*Demand [% to 1991]*	*Fattened pigs [% to BAS]*	*Production [% to BAS]*	*Demand [% to BAS]*	Net trade [Δ to BAS]
Austria	4734	477	468	9	*2%*	*-2%*	*-5%*	*4%*	*1%*	17
Belgium-Lux.	10793	1027	504	523	*16%*	*2%*	*9%*	*15%*	*9%*	108
Denmark	24332	1873	325	1548	*47%*	*6%*	*1%*	*2%*	*-17%*	86
Finland	2270	199	177	21	*25%*	*22%*	*-16%*	*-8%*	*13%*	-40
France	25594	2336	2191	144	*26%*	*4%*	*12%*	*13%*	*7%*	145
Germany	41172	4163	4485	-321	*10%*	*2%*	*10%*	*15%*	*-1%*	689
Greece	2065	131	302	-170	*-14%*	*44%*	*-18%*	*-22%*	*22%*	-96
Ireland	2703	223	159	63	*32%*	*19%*	*-14%*	*-9%*	*46%*	-93
Italy	12415	1498	2274	-776	*23%*	*24%*	*6%*	*8%*	*19%*	-325
Netherlands	16135	1491	604	887	*-17%*	*-9%*	*-8%*	*-1%*	*-3%*	7
Portugal	4944	330	457	-127	*26%*	*60%*	*-5%*	*-9%*	*22%*	-130
Spain	36577	3202	2666	536	*71%*	*38%*	*16%*	*20%*	*3%*	556
Sweden	3189	287	318	-30	*7%*	*18%*	*-18%*	*-9%*	*5%*	-41
United Kingdom	8707	681	1258	-577	*-31%*	*-9%*	*-14%*	*-4%*	*11%*	-169
EU15	195630	17919	16187	1731	*18%*	*11%*	*5%*	*10%*	*6%*	715
Cyprus	668	56	54	2	*71%*	*78%*	*19%*	*16%*	*52%*	-19
Czech Republic	4421	439	463	-24	*-39%*	*-35%*	*-26%*	*-17%*	*1%*	-82
Estonia	481	40	49	-8	*-49%*	*-37%*	*-21%*	*-12%*	*13%*	-11
Hungary	4992	510	468	42	*-41%*	*-37%*	*-22%*	*-14%*	*-16%*	4
Latvia	421	33	38	-5	*-70%*	*-68%*	*-32%*	*-23%*	*-18%*	-1
Lithuania	1290	100	117	-17	*-47%*	*-24%*	*-3%*	*8%*	*31%*	-28
Malta	109	9	13	-5	*15%*	*7%*	*-5%*	*1%*	*21%*	-3
Poland	22780	1989	1883	105	*3%*	*-3%*	*13%*	*26%*	*8%*	360
Slovac Republic	1702	152	171	-20	*-36%*	*-30%*	*-42%*	*-49%*	*-16%*	-46
Slovenia	411	36	55	-19	*-16%*	*-2%*	*-31%*	*-21%*	*3%*	-10
10 New MS	37275	3363	3311	52	*-20%*	*-19%*	*-1%*	*9%*	*4%*	165
Bulgaria	1000	91	105	-14	*-75%*	*-69%*	*-71%*	*-67%*	*-37%*	-22
Romania	5836	517	639	-123	*-38%*	*-21%*	*-37%*	*-30%*	*12%*	-231
Bulgaria/Romania	6835	608	744	-137	*-50%*	*-35%*	*-42%*	*-35%*	*5%*	-253
EU27	239740	21889	20243	1646	*6%*	*2%*	*3%*	*8%*	*6%*	626

Even though the pig sector is not a big source of CH_4 it is an important source of nitrogen and hence N_2O. In the past several large producers have developed with strong dynamics, most importantly Denmark and Spain. However, national expert information has confirmed that increasingly stringent environmental regulation will bring this growth to a halt (Denmark) or strongly dampen the future growth of supply. This is often put forward to explain the decline of Dutch pig production whereas the drop in the UK and Greece may have more to do with a loss in competitiveness. Demand growth has been a reliable support for the evolution of EU15 pork markets in the past, but this stimulus may be seen to weaken in the projection period.

Pork markets in the EU12 have suffered during the transition phase as may be read from the past changes but an important exception is Poland's pork sector that turned out quite resistant in the evolving market economy and may be expected to grow strongly and come close to France soon in terms of the pig population. While both supply and demand growth is losing momentum, as supply

growth is still ahead of demand growth EU-27 net exports would tend to increase, by 0.6 million tons in 2020 relative to the base year.

Table 8.12: Poultry sector development by EU MS, base year compared to the baseline year 2020

	Base year (2004)						Reference year (2020)			
	Fattened poultry [1000 hd]	Production [1000 t]	Demand [1000 t]	Net trade [1000 t]	*Production [% to 1991]*	*Demand [% to 1991]*	*Fattened poultry [% to BAS]*	*Production [% to BAS]*	*Demand [% to BAS]*	Net trade [Δ to BAS]
Austria	56	113	156	-43	*25%*	*40%*	*6%*	*18%*	*28%*	-24
Belgium-Lux.	66	178	74	104	*-1%*	*-60%*	*27%*	*38%*	*-58%*	111
Denmark	131	213	123	90	*50%*	*92%*	*24%*	*28%*	*49%*	0
Finland	52	86	83	3	*141%*	*134%*	*24%*	*23%*	*31%*	-6
France	900	1991	1383	608	*12%*	*11%*	*2%*	*14%*	*8%*	165
Germany	594	1143	1489	-346	*99%*	*53%*	*27%*	*21%*	*21%*	-82
Greece	91	171	233	-63	*6%*	*38%*	*2%*	*11%*	*13%*	-12
Ireland	111	125	115	9	*39%*	*39%*	*-9%*	*-9%*	*18%*	-32
Italy	381	1039	982	58	*-7%*	*-14%*	*-10%*	*4%*	*-18%*	215
Netherlands	274	527	278	249	*-4%*	*-4%*	*3%*	*5%*	*-1%*	28
Portugal	253	284	300	-16	*40%*	*49%*	*18%*	*5%*	*-4%*	26
Spain	647	1342	1384	-42	*53%*	*50%*	*28%*	*26%*	*6%*	263
Sweden	71	104	126	-22	*85%*	*120%*	*27%*	*16%*	*43%*	-38
United Kingdom	851	1574	1725	-152	*30%*	*35%*	*12%*	*25%*	*20%*	48
EU15	4477	8890	8452	438	*26%*	*25%*	*12%*	*17%*	*10%*	660
Cyprus	16	33	35	-2	*65%*	*70%*	*21%*	*30%*	*29%*	0
Czech Republic	192	242	255	-12	*140%*	*169%*	*37%*	*32%*	*31%*	-2
Estonia	6	14	26	-11	*-39%*	*-20%*	*-21%*	*-15%*	*4%*	-3
Hungary	148	364	262	102	*37%*	*91%*	*-5%*	*5%*	*16%*	-24
Latvia	0	1	22	-21	*-93%*	*-42%*	*38%*	*-22%*	*-21%*	4
Lithuania	19	38	61	-23	*19%*	*37%*	*14%*	*12%*	*41%*	-21
Malta	3	7	10	-4	*25%*	*95%*	*-10%*	*-1%*	*66%*	-7
Poland	459	934	842	92	*176%*	*166%*	*37%*	*28%*	*38%*	-61
Slovac Republic	58	88	97	-9	*83%*	*96%*	*22%*	*31%*	*31%*	-3
Slovenia	27	60	54	6	*-4%*	*67%*	*5%*	*17%*	*25%*	-4
10 New MS	928	1781	1664	117	*95%*	*116%*	*27%*	*23%*	*31%*	-120
Bulgaria	39	63	94	-30	*-37%*	*8%*	*0%*	*-12%*	*21%*	-27
Romania	192	292	395	-103	*-12%*	*9%*	*1%*	*10%*	*33%*	-102
Bulgaria/Romania	231	355	489	-133	*-18%*	*9%*	*1%*	*6%*	*31%*	-129
EU27	5637	11027	10605	421	*31%*	*33%*	*14%*	*18%*	*15%*	411

Poultry markets have shown the strongest growth in the past among all meats, both on the supply and demand side. With a few exceptions poultry production has also grown in the EU12, where a strong decline of animal production in the recent past was experienced. However, this dynamic is likely to even out. On the demand side saturation may be seen to clearly dampen the future demand growth, in particular in EU15 countries. On the supply side it appears that environmental regulations also limit the growth of the poultry sector which is in line with expert information from several MS. Nonetheless, supply growth would tend to run ahead of demand growth such that net exports would increase by 0.4 million tons which is up by a factor of 2 against the base year.

Table 8.13: Cereal sector development by EU MS, base year compared to the baseline year 2020

	Base year (2004)						Reference year (2020)				
	Area [1000 hd]	Production [1000 t]	Demand [1000 t]	Net trade [1000 t]	*Area [% to 1991]*	*Demand [% to 1991]*	*Area [% to BAS]*	*Yield [% to BAS]*	*Production [% to BAS]*	*Demand [% to BAS]*	Net trade [Δ to BAS]
Austria	807	5041	5007	34	-13%	8%	-13%	19%	4%	9%	-236
Belgium-Lux.	342	2683	5704	-3022	-1%	32%	-2%	11%	9%	27%	-1269
Denmark	1487	9372	9019	353	-4%	36%	4%	7%	12%	5%	640
Finland	1203	4010	3628	382	15%	55%	4%	14%	18%	8%	445
France	9150	63728	31838	31890	0%	1%	-2%	15%	13%	7%	6131
Germany	6876	46604	40465	6138	5%	15%	0%	20%	21%	10%	5700
Greece	1261	4461	6034	-1573	-11%	35%	-19%	18%	-4%	-1%	-160
Ireland	297	2284	3007	-723	-2%	46%	-6%	14%	7%	16%	-326
Italy	4140	20921	26880	-5960	-1%	16%	-5%	22%	16%	6%	1585
Netherlands	223	1751	7601	-5851	17%	66%	7%	14%	22%	34%	-2208
Portugal	431	1162	4448	-3287	-44%	39%	-41%	29%	-24%	2%	-382
Spain	6601	20581	28307	-7726	-14%	38%	-9%	24%	13%	17%	-2331
Sweden	1092	5494	4447	1047	-10%	1%	-9%	11%	1%	-13%	610
United Kingdom	3050	21872	21237	635	-13%	15%	-4%	1%	-3%	13%	-3545
EU15	36962	209963	197623	12339	-5%	20%	-4%	17%	12%	10%	4654
Cyprus	68	109	796	-687	38%	15%	-23%	-2%	-24%	8%	-86
Czech Republic	1611	7423	6383	1040	-1%	-17%	3%	12%	15%	-11%	1824
Estonia	269	709	759	-49	-36%	-31%	34%	50%	101%	511%	-3157
Hungary	2892	14113	10690	3423	5%	-29%	3%	9%	13%	-4%	2187
Latvia	443	1169	986	183	-31%	-35%	7%	22%	30%	-6%	406
Lithuania	900	3039	2210	830	-12%	-30%	0%	36%	36%	21%	616
Malta	0	0	161	-160	-88%	14%	-45%	14%	-37%	10%	-16
Poland	8289	29150	28882	268	-5%	-8%	-7%	14%	6%	-8%	4171
Slovac Republic	806	3307	2724	583	0%	-30%	-1%	10%	8%	-17%	749
Slovenia	98	526	983	-457	-16%	-13%	-13%	8%	-6%	-28%	238
10 New MS	15377	59546	54574	4972	-5%	-17%	-2%	15%	12%	0%	6932
Bulgaria	1721	6231	5899	332	-23%	-43%	-17%	28%	6%	-21%	1629
Romania	5854	19653	19535	118	-3%	-4%	-15%	6%	-10%	-13%	644
Bulgaria/Romania	7574	25884	25434	450	-8%	-17%	-16%	11%	-6%	-15%	2273
EU27	59913	295392	277631	17761	-5%	6%	-5%	17%	10%	6%	13859

Animal sector developments are linked to the crop sector via feed demand which is clearly dominating food demand in the EU-27. The net effect on cereals markets of declining cattle and sheep sectors and expanding pigs and poultry sectors, supplemented with a moderate growth in food demand is an increase of total demand. Production growth is slightly stronger on the EU15 or EU-27 level and mainly based on yield growth as cereal area is slightly declining. As cereals occupy the largest share of arable land such a decline may be expected with a small share of utilised agricultural area (UAA) lost each year to non-agricultural purposes. Yield growth is projected to be quite similar in EU15 and EU12 countries with the extreme values often influenced by composition effects (low yield growth in Cyprus due to reallocation in favour of durum, high yield growth in Estonia due to reallocation away from oats). With supply outpacing demand net exports of EU-27 would increase by nearly 14 million tons.

Table 8.14: Fodder sector development by EU MS, base year compared to the baseline year 2020

	Base year (2004)						Reference year (2020)			
	Fodder area [1000 ha]	Fodder prod. [1000 t]	Grassland [1000 ha]	Grass prod. [1000 t]	*Fodder area [% to 1991]*	*Grassland [% to 1991]*	*Fodder area [% to BAS]*	*Fodder prod. [% to BAS]*	*Grassland [% to BAS]*	*Grass prod [% to BAS]*
Austria	2116	47143	1882	37976	-3%	-4%	-1%	5%	-1%	7%
Belgium-Lux.	869	35166	591	20253	-1%	-5%	-4%	-3%	-1%	-6%
Denmark	673	33504	183	6235	-15%	-12%	-9%	-5%	-6%	-4%
Finland	633	13033	605	9016	0%		-2%	-4%	-3%	-15%
France	14841	382493	10013	201635	-8%	-9%	-6%	4%	-2%	4%
Germany	6663	272820	4936	167775			-9%	-1%	-3%	3%
Greece	2093	22167	1789	16713	18%	1%	6%	-7%	3%	-13%
Ireland	3939	151084	3098	109450	-3%	-16%	0%	11%	-10%	-7%
Italy	6211	99432	4380	51230	-15%	-3%	-2%	-2%	5%	5%
Netherlands	1217	56560	776	34863	-6%	-26%	2%	1%	-10%	-16%
Portugal	2036	29591	1482	21801	11%	29%	15%	21%	25%	30%
Spain	11518	151503	10459	121749	2%	5%	-1%	4%	0%	5%
Sweden	1519	43352	500	10651	13%	-12%	2%	15%	-10%	11%
United Kingdom	11349	337605	9972	272164	-6%	-3%	-3%	-1%	-1%	0%
EU15	65675	1675454	50665	1081511	7%	-4%	-2%	2%	0%	1%
Cyprus	25	301	0	2	15%	-90%	59%	20%	-10%	-40%
Czech Republic	1279	27653	862	12385	-34%	0%	-18%	-18%	-1%	-5%
Estonia	430	8737	247	4388	-51%	1%	-25%	6%	-10%	20%
Hungary	1439	26210	1067	14031	-23%	-9%	-22%	2%	-9%	22%
Latvia	954	15072	621	8898	-44%	-26%	-22%	2%	-7%	23%
Lithuania	1277	25722	940	16705	-38%	3%	-20%	10%	-10%	21%
Malta	5	47	0	0	11%		11%	-14%		
Poland	4122	95392	3340	50648	-30%	-14%	-12%	-2%	-6%	-3%
Slovac Republic	859	13858	611	7269	-28%	-21%	-15%	-30%	0%	-36%
Slovenia	383	6095	320	4243	-3%	-8%	3%	8%	0%	-1%
10 New MS	10774	219085	8007	118570	-32%	-12%	-16%	-3%	-6%	4%
Bulgaria	1963	25815	1827	20247	-31%	-9%	11%	27%	17%	37%
Romania	5717	103964	4810	82492	-11%	1%	-1%	8%	8%	15%
Bulgaria/Romania	7681	129780	6637	102739	-18%	-2%	2%	11%	10%	20%
EU27	84130	2024319	65309	1302820	-3%	-5%	-4%	2%	0%	3%

While cereal demand is influenced by the whole animal sector, fodder demand is evidently dominated by ruminants. Another difference is that there is no trade of fodder across countries such that any additional demand has to be met in the region. Finally another driver is that EU policy requires that permanent grassland, the largest part of fodder area, must not decline in significant amounts in view of the environmental benefits expected from it. As a consequence we would typically expect only moderate changes in grassland and hence fodder areas in the projection period. The largest losses of grassland in EU15 are expected in countries that saw also considerable losses in the past (Denmark, Ireland, Netherlands, Sweden). Note that fodder area has declined considerably in EU12 countries in the historical period. This is in line with the decline of their cattle and sheep sectors, but it needs to be acknowledged that some changes may have been influenced by data weaknesses related to the 1991 data. The highest percentage decline in Cyprus grassland is due to very small initial grassland.

Other changes in the area allocation between crops are not reported in detail here. While they may have an influence on emissions if more intensive crops are expanding at the expense of less intensive ones (like arable fodder), the key drivers for changes in emissions are in the animal sector that has been reviewed above.

8.3.2.2 Projection of agricultural emission inventories between 2004 and 2020

The development of emissions of individual gases and $CO_{2\text{-eq}}$ for all EU Member States from the 2003-2005 base period to the projection year 2020 are presented in the following table. With the exemption of Malta, Spain and the Netherlands, a reduction in total emissions can be observed in all countries. The current baseline implies 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 from 2004 to 2020 is more significant in absolute terms.

Table 8.15: Change in emissions per EU Member State between 2004 and 2020

	Base Year (BAS, 2004)				Baseline (REF, 2020)			
	Methane	Nitrous Oxide	CO2 equivalents	Ammonia	Methane	Nitrous Oxide	CO2 equivalents	Ammonia
	[1000t]	[1000t]	[1000t]	[1000t]	[% to BAS]	[% to BAS]	[% to BAS]	[% to BAS]
Austria	204.3	12.5	8158.0	47.7	-15.9	0.0	-8.4	-1.0
Belgium-Lux.	263.9	18.1	11152.9	70.0	-4.9	0.6	-2.1	5.0
Denmark	254.3	22.2	12225.0	98.9	-21.3	-11.6	-15.8	-6.8
Finland	95.6	24.8	9703.0	22.0	-14.7	-3.9	-6.2	-7.6
France	1784.3	146.2	82776.3	499.3	-14.5	4.5	-4.1	-0.7
Germany	1535.1	110.8	66586.0	500.7	-21.1	4.4	-8.0	0.8
Greece	156.2	10.5	6548.0	30.8	-7.3	-15.1	-11.2	-7.7
Ireland	563.3	37.0	23299.5	106.3	-6.3	6.3	-0.1	0.0
Italy	844.1	55.0	34759.3	323.0	-6.3	-5.0	-5.6	0.0
Netherlands	428.2	34.2	19603.8	101.8	3.3	-2.7	0.0	-1.0
Portugal	172.3	10.3	6813.4	52.4	-13.8	-9.6	-11.9	-11.1
Spain	889.3	67.2	39501.7	298.0	0.6	7.5	4.2	7.2
Sweden	182.4	20.7	10246.7	48.5	-31.8	-3.4	-14.0	-8.8
United Kingdom	1046.7	127.1	61387.3	230.6	-12.1	-4.7	-7.3	-2.7
EU15	8420.0	696.6	392760.9	2430.2	-11.7	0.4	-5.1	-0.2
Cyprus	12.8	0.8	503.3	5.1	-1.3	-1.3	-1.4	6.0
Czech Republic	135.7	14.3	7279.4	59.5	-53.7	-8.0	-25.9	-14.5
Estonia	26.4	2.2	1236.6	7.9	-47.8	6.8	-17.7	-27.0
Hungary	97.4	18.7	7841.3	68.5	-42.2	2.1	-9.5	-8.3
Latvia	37.0	4.7	2234.0	12.1	-42.1	-2.1	-16.0	-15.6
Lithuania	84.9	9.9	4842.0	27.4	-34.9	5.9	-9.1	-11.6
Malta	2.1	0.1	87.9	1.1	5.3	14.3	8.6	7.4
Poland	533.8	70.5	33051.6	260.7	-27.5	-2.5	-11.0	-0.9
Slovac Republic	51.4	4.9	2586.2	19.2	-49.1	-8.4	-25.4	-28.3
Slovenia	44.5	2.9	1826.6	13.3	-18.6	-5.6	-12.2	-9.8
10 New MS	1026.0	128.9	61488.8	474.6	-34.3	-1.9	-13.3	-6.3
Bulgaria	105.5	9.0	5001.7	26.4	-34.2	-12.0	-21.8	-18.2
Romania	414.4	26.3	16839.0	104.6	-30.2	-9.6	-20.2	-12.7
Bulgaria/Romania	519.9	35.2	21840.7	130.9	-31.0	-10.2	-20.6	-13.8
EU27	9965.9	860.7	476090.4	3035.7	-15.0	-0.4	-6.8	-1.7

Looking into the emission components in the reference scenario we observe that the highest decrease is projected to be achieved by methane emissions (-15%), while the reduction in nitrous oxide is projected to remain at -0.4. Ammonia, in turn, is reduced by -1.7%.

For the EU15 the reduction of methane emissions in the reference scenario is projected at -11.7%, with highest reductions achieved in Denmark (-21.3%), Germany (-21.1%) and Sweden (-31.8%) whereas Spain and the Netherlands are projected to increase methane emissions by 0.6 and 3.3 respectively. The EU10 and Bulgaria/Romania are projected to experience methane emission reductions of -34.3% and -31% respectively with Malta being the only MS increasing methane

emissions (+5.3%) and Cyprus (-1.3%) and Slovenia (-18.6%) being the only MS achieving reductions less than 20%.

The changes in emissions of nitrous oxide are projected to be -0.4% for the EU10, -10.2% for Romania/Bulgaria and +0.4% for the EU15. However, in the EU10, Estonia, Hungary, Lithuania and Malta are projected to increase nitrous oxide emissions. From the EU15, the only countries projected to experience nitrous oxide emission increases are France, Germany, Ireland and Spain.

The total reduction of ammonia emissions is projected to be -1.7% at EU-27 level, with EU15 contributing with a slight reduction of -0.2% and EU10 and Bulgaria/Romania contributing with -6.3% and -13.8% respectively. The countries showing increases in ammonia emissions are Spain, Belgium-Luxemburg, Germany, Cyprus and Malta.

Table 8.16: Change in emissions per inventory position for the EU between 2004 and 2020

	Base Year (BAS, 2004)				Baseline (REF, 2020)			
	EU15 [t]	EU10 [t]	BUR [t]	EU27 [t]	EU15 [% to BAS]	EU10 [% to BAS]	BUR [% to BAS]	EU27 [% to BAS]
Methane emissions from enteric fermentation (IPCC)	6918.1	885.2	474.7	8278.1	-13.2	-37.2	-30.8	-16.8
Methane emissions from manure management (IPCC)	1501.9	140.8	45.2	1687.8	-4.7	-16.0	-33.4	-6.4
Methane emissions	8420.0	1026.0	519.9	9965.9	-11.7	-34.3	-31.0	-15.0
Direct nitrous oxide emissions stemming from manure managment and application except grazings (IPCC)	178.2	34.4	9.3	221.9	-2.5	-8.8	-13.7	-3.9
Direct nitrous oxide emissions stemming from manure management (only housing and storage) (IPCC)	*106.7*	*22.7*	*6.7*	*136.1*	*-3.2*	*-9.1*	*-13.7*	*-4.7*
Direct nitrous oxide emissions stemming from manure application on soils except grazings (IPCC)	*71.5*	*11.7*	*2.6*	*85.8*	*-1.3*	*-8.3*	*-13.3*	*-2.6*
Direct nitrous oxide emissions from anorganic fertilizer application (IPCC)	179.2	39.3	7.6	226.1	2.6	8.1	-16.4	2.9
Direct nitrous oxide emissions from crop residues (IPCC)	64.5	11.6	7.3	83.4	14.6	5.2	2.6	12.2
Direct nitrous oxide emissions from nitrogen fixing crops (IPCC)	12.3	1.7	0.9	14.8	-0.5	-33.9	-16.5	-5.1
Direct nitrous oxide emissions from atmosferic deposition (IPCC)	15.3	3.0	1.9	20.2	-1.5	-3.0	-0.5	-1.7
Indirect nitrous oxide emissions from ammonia volatilisation (IPCC)	42.0	7.9	2.3	52.2	-0.1	-4.1	-12.9	-1.3
Indirect nitrous oxide emissions from leaching (IPCC via Miterra)	16.1	3.7	1.0	20.8	-6.0	-2.7	-31.7	-6.6
Direct nitrous oxide emissions from cultivation of histosols (IPCC via Miterra)	112.4	21.2	0.2	133.8	-3.2	-2.6	0.0	-3.1
Nitrous oxide emissions	696.6	128.9	35.2	860.7	0.4	-1.9	-10.2	-0.4
Carbon dioxide equivalent emissions (global warming potential)	392760.9	61488.8	21840.7	476090.4	-5.1	-13.3	-20.6	-6.8
Ammonia emissions	2430.2	474.6	130.9	3035.7	-0.2	-6.3	-13.8	-1.7

Note: BUR = Bulgaria and Romania

As can be seen in Table 8.16, the general emission reduction at EU level is mostly based on emissions linked to ruminants (CH_4 from digestion and N_2O from manure management). These

emission reductions can therefore mostly be attributed to the reduced policy incentives for beef cattle and sheep/goats after the conversion of coupled supports for beef production into (mainly) decoupled payments, and the reform in the dairy market. The adjustments in emissions are generally larger in the EU12 compared to EU15. Crop yields continue to grow moderately, provoking an increase in emissions linked to crop residues, and to lesser extent, to the application of mineral nitrogenous fertilizers. That the latter contributes to a lesser extend to emission increases can be attributed to a more efficient use of both organic and mineral fertilizers.

At EU-27 level the projected methane emission reductions of -15% is mainly due to the reduction of methane emissions coming from the enteric fermentation (-16%), while the methane emission reduction from manure management accounts for only -6%. The EU15 and EU10 present a similar distribution of methane emission reduction among the components, while Bulgaria/Romania are projected to achieve a higher methane emission reduction coming from manure (-33.4%) than from the enteric fermentation (-30.8%).

Looking at the nitrous oxide emissions at EU-27 level, there are two components expected to be responsible for emission increases, direct nitrous oxide emissions from anorganic fertilizer application (+2.9%) and direct nitrous oxide emissions from crop residues (+12.2%). The EU15 presents a similar picture of 2.6% emission increase from anorganic fertilizer application and 14.6% increase from crop residues. In Bulgaria/Romania the nitrous oxide emissions from anorganic fertilizer application are projected to decrease by 16.4% while emissions from crop residues would increase by 2.6%. The EU10 presents the contrary picture to the EU15, as the increases in nitrous oxide emissions attributed to anorganic fertilizer application are expected to be higher than the emissions from crop residues (8.1% and 5.2% respectively).

8.3.3. Concluding remarks

The reference scenario can be interpreted as 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. The baseline assumes status-quo policy and includes future policy changes already agreed and scheduled in the current legislation, based on the information available at the end of June 2010. The changes in legislation proposed or adopted since that date have not been taken into account. The reference scenario as presented here can be interpreted as a projection in time, describing how the European agricultural sector (and thus GHG emissions of the agricultural sector) may develop under the status quo policy and including all future policy changes already agreed and scheduled in the current legislation. It has to be kept in mind that the agricultural sector is included in the EU GHG emission reduction obligation of the so-called climate and energy package of 2009. However, so far there are no explicit policy measures 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, and the results of the emission projections are solely linked to the development of agricultural markets.

The results of the agricultural market and emission projection presented in the reference scenario should be seen as a benchmark for assessing the impact of the implementation of GHG emission abatement policies that explicitly force farmers in the EU-27 to reach certain GHG emission

reduction targets. The policy scenarios analysed in the next chapter are characterised by a target of 20% GHG emission reduction in the year 2020 compared to EU-27 emissions in the base year.

According to the projections of the reference scenario the EU-27 will not achieve a GHG emission reduction of 20% without implementing specific policy measures. Looking at MS level we can conclude that according to the projections additional measures would be needed in almost all EU15 MS if the objective of an emission reduction of 20% would be applied on MS level, methane and nitrous oxide considered. In the EU12, the situation is different, since several countries autonomously already reduce emissions in the reference scenario below the 20% objective. Furthermore, the emission projection results indicate that an emission reduction commitment based on historical emissions would not be necessarily binding for all MS.

8.4. Assessment of the impact of selected policy mitigation scenarios

8.4.1. Emission Standard Scenario (STD)

With the Emission Standard Scenario (STD) we are interested in looking at the effects of a regionally homogeneously distributed emission cap of -20% on GHG emissions. This scenario serves as starting point for our scenario analysis of mitigation policies in agriculture. It is important to mention, that this scenario does not reflect any existing EU policy, since it distributes the burden of emission abatement equally amongst all regions[19]. In other words, under this hypothetical scenario each region is forced to reduce emissions by 20%, regardless of their historical emissions, costs of production or type of specialization when facing the emission abatement (i.e. their differentiated marginal abatement costs according to specialization and location are not taken into account).

8.4.1.1 Changes in GHG emission

Table 8.17 presents the changes in GHG emissions between the emission standard scenario and the baseline (changes in year 2020). The first figure to look at is the total reduction of GHG emissions for the EU-27 (-13.7%), which is the additional emission reduction commitment necessary to achieve an overall -20% 'cap' on GHG emissions. As we saw in the previous chapter, in the baseline the fall in GHG emissions is -6.8%.

[19] Thus, the ESD is not taken into account in this scenario exercise.

Table 8.17: Change in emissions per EU Member State according to the emission standard scenario

	Baseline (REF, 2020)				Emission standard in agriculture (STD, 2020)			
	Methane [t]	Nitrous Oxide [t]	CO2 equivalents [t]	Ammonia [t]	Methane [% to REF]	Nitrous Oxide [% to REF]	CO2 equivalents [% to REF]	Ammonia [% to REF]
Austria	171.8	12.5	7472.7	47.2	-13.6	-11.1	-12.3	-8.6
Belgium-Lux.	251.1	18.2	10915.8	73.6	-16.3	-16.9	-16.6	-12.4
Denmark	200.1	19.6	10287.4	92.2	-4.3	-3.2	-3.6	-0.5
Finland	81.6	23.8	9103.2	20.3	-6.8	-16.4	-14.6	-4.6
France	1526.0	152.8	79412.4	495.7	-15.1	-16.4	-15.9	-10.8
Germany	1210.5	115.7	61275.5	504.5	-9.1	-14.9	-12.5	-5.6
Greece	144.8	9.0	5814.9	28.5	-9.8	-8.9	-9.4	-7.1
Ireland	527.7	39.3	23276.5	106.4	-20.3	-18.7	-19.5	-19.1
Italy	791.3	52.2	32800.9	322.9	-14.2	-15.0	-14.6	-10.9
Netherlands	442.2	33.3	19609.2	100.8	-16.2	-21.4	-18.9	-18.7
Portugal	148.4	9.3	6005.9	46.6	-7.4	-10.7	-9.0	-4.1
Spain	894.8	72.2	41171.3	319.3	-23.1	-22.0	-22.5	-14.2
Sweden	124.5	20.0	8811.7	44.3	-3.4	-8.1	-6.7	-1.2
United Kingdom	919.5	121.2	56876.3	224.5	-8.6	-15.2	-12.9	-5.4
EU15	7434.2	699.1	372833.6	2426.5	-13.8	-15.9	-15.0	-9.6
Cyprus	12.6	0.8	496.2	5.4	-20.6	-14.7	-17.6	-14.0
Czech Republic	62.9	13.1	5393.2	50.9	3.4	1.9	2.3	4.2
Estonia	13.8	2.4	1018.2	5.7	-3.9	0.0	-1.3	-6.3
Hungary	56.3	19.1	7099.3	62.8	-8.1	-11.4	-10.9	-3.9
Latvia	21.4	4.6	1876.9	10.2	-1.1	-3.7	-3.2	-0.6
Lithuania	55.3	10.5	4399.9	24.2	-4.9	-12.3	-10.4	-4.9
Malta	2.2	0.2	95.5	1.2	-28.0	-25.0	-25.2	-21.6
Poland	387.1	68.7	29419.2	258.4	-11.0	-11.3	-11.2	-7.6
Slovac Republic	26.2	4.5	1928.8	13.7	6.8	2.5	3.8	4.7
Slovenia	36.2	2.7	1604.0	12.0	-7.7	-8.5	-8.0	-6.4
10 New MS	673.9	126.4	53331.1	444.5	-7.8	-9.0	-8.7	-5.1
Bulgaria	69.4	7.9	3910.0	21.6	0.8	-0.9	-0.2	1.3
Romania	289.2	23.7	13432.2	91.3	-1.2	-0.7	-0.9	0.6
Bulgaria/Romania	358.7	31.7	17342.2	112.9	-0.8	-0.7	-0.8	0.7
EU27	8466.8	857.1	443506.9	2984.0	-12.8	-14.4	-13.7	-8.5

It is interesting to see in Table 8.17 how the model allocates the emission 'cap' differently to gases and MS after clearance of agricultural markets. First of all, higher emission reductions are observed in the EU15 than in the EU10 and BUR. This is due to the fact that several EU10 countries do not need to face the full 'cap' (on average -8.7%), since their baseline emissions are considerably lower than the base year emissions (e.g. in Czech and Slovak Republic they are even allowed to increase emissions compared to the baseline projections). Within the EU15 aggregate, higher emission reductions are coupled to lower degree of production substitution possibilities and lower production margins (e.g. beef production in Spain and Ireland). Secondly, in EU-27 the N_2O emissions (-14.4%) are on average more affected than CH_4 emissions (-12.8%). This has to do with the fact that on average it is more costly for farmers to achieve the emission standard through the reduction of CH_4 emission activities compared to N_2O-emitting activities. By looking at Table 8.18 we can observe that the highest reductions (taking absolute terms into account) are achieved in N_2O emissions from mineral fertilizer application. Therefore, an optimal strategy for farmers to cope

with the emission standard is to move to more extensive arable and fodder production (less nitrogen input required).

Table 8.18: Change in emissions per inventory position for the EU according to the emission standard scenario

	Baseline (REF, 2020)				Emission Standard (STD, 2020)			
	EU15	EU10	BUR	EU27	EU15	EU10	BUR	EU27
	[1000t]	[1000t]	[1000t]	[1000t]	[% to REF]	[% to REF]	[% to REF]	[% to REF]
Methane emissions from enteric fermentation (IPCC)	6002.4	555.7	328.6	6886.6	-15.0	-8.3	-1.0	-13.8
Methane emissions from manure management (IPCC)	1431.8	118.2	30.1	1580.1	-8.9	-5.6	0.5	-8.5
Methane emissions	7434.2	673.9	358.7	8466.8	-13.8	-7.8	-0.8	-12.8
Direct nitrous oxide emissions stemming from manure managment and application except grazings (IPCC)	173.8	31.4	8.0	213.2	-11.0	-6.0	0.3	-9.8
Direct nitrous oxide emissions stemming from manure management (only housing and storage) (IPCC)	*103.2*	*20.7*	*5.8*	*129.6*	*-12.4*	*-6.4*	*0.0*	*-10.9*
Direct nitrous oxide emissions stemming from manure application on soils except grazings (IPCC)	*70.6*	*10.7*	*2.2*	*83.5*	*-8.9*	*-5.1*	*0.0*	*-8.2*
Direct nitrous oxide emissions from anorganic fertilizer application (IPCC)	183.8	42.5	6.4	232.7	-18.8	-10.2	2.2	-16.6
Direct nitrous oxide emissions from crop residues (IPCC)	73.9	12.2	7.5	93.6	-17.2	-11.3	-0.4	-15.0
Direct nitrous oxide emissions from nitrogen fixing crops (IPCC)	12.2	1.1	0.7	14.0	-20.1	-10.1	-1.4	-18.4
Direct nitrous oxide emissions from atmosferic deposition (IPCC)	15.0	2.9	1.9	19.8	-8.4	-4.1	0.0	-6.9
Indirect nitrous oxide emissions from ammonia volatilisation (IPCC)	41.9	7.6	2.0	51.5	-11.3	-6.2	0.5	-10.1
Indirect nitrous oxide emissions from leaching (IPCC via Miterra)	15.1	3.6	0.7	19.4	-32.1	-42.6	-46.5	-34.5
Direct nitrous oxide emissions from cultivation of histosols (IPCC via Miterra)	108.8	20.7	0.2	129.7	-15.8	-6.3	0.0	-14.3
Nitrous oxide emissions	699.1	126.4	31.7	857.1	-15.9	-9.0	-0.7	-14.4
Carbon dioxide equivalent emissions (global warming potential)	372833.6	53331.1	17342.2	443506.9	-15.0	-8.7	-0.8	-13.7
Ammonia emissions	2426.5	444.5	112.9	2984.0	-9.6	-5.1	0.7	-8.5

8.4.1.2 Analysis of economic effects

An emission standard in agriculture provokes an effect similar to the effects observed in regulated markets in the EU, such as the sugar and milk common market organizations: reduction in production, extensification effects and increases in prices, frequently followed by increases in income. Nevertheless, from a welfare perspective, the net effect is mostly negative due to higher prices faced by consumers which may outweigh the gains by producers.

The marginal emission abatement costs faced by the producers are the "emission quota rents", which vary across MS and production activities depending on the cost structures faced by producers. Compared to an emission trading system (see chapter below), these cost differences impose a high burden within the regulated sector (i.e. high income activities or high productive regions suffer more). Table 8.19 shows how the effect of the emission standard is distributed across activities. Larger drops in production in the cattle sector (especially beef meat activities with herd sizes dropping by -26%) lead to higher prices and higher income (+68% for all cattle activities). This is also the case for the arable sector, with utilised agricultural area falling by -5% (the increase in fallow land does not fully compensate the losses in fodder and arable areas) and income increasing on average by 18.5%.

Table 8.19: Change in income, area, yield and supply for the EU-27 for activity aggregates according to the emission standard scenario

	Baseline (REF, 2020)				Emission Standard (STD, 2020)			
	Income	Area/ Herd sizes	Yield	Supply	Income	Area/ Herd sizes	Yield	Supply
	[Eur ha or hd]	[1000 ha or hd]	[kg/ha or hd]	[1000 t]	*[% to REF]*	*[% to REF]*	*[% to REF]*	*[% to REF]*
Cereals	550	56737	5750	326227	20.2%	-6.9%	0.5%	-6.4%
Oilseeds	328	10034	2917	29266	27.6%	-5.9%	-0.9%	-6.7%
Other arable crops	864	8185	19874	162678	23.3%	-4.8%	-8.5%	-12.9%
Vegetables and Permanent crops	6131	15092	11525	173932	1.1%	0.4%	-0.3%	0.1%
Fodder activities	274	80976	23060	1867313	1.0%	-8.8%	-12.4%	-20.0%
Set aside and fallow land	135	14976			6.6%	11.4%		
Utilized agricultural area	1287	187450	13656	2559779	18.5%	-5.4%	-11.5%	-16.3%
All cattle activities	461	84745	93	7907	68.0%	-16.3%	1.9%	-14.8%
Beef meat activities	152	27015	362	9785	173.1%	-25.9%	-3.5%	-28.5%
Other animals	110	394741	776	306251	25.6%	-6.6%	2.8%	-4.0%

Taking into account the considerable emission cap introduced, cereal areas are expected to decrease only moderately (-7%) in the EU-27, with proportionally higher decreases in the EU15 than the EU12. With almost no changes in yields at EU-27, the reduction in cereals area results in a decrease in cereal production of -6.4%. The net exporter position of the EU-27 (mostly coming from the EU15) is weakened, since demand drops less than supply: imports of cereals decrease by -3 MM t cereals and exports by -10.6 MM t (net effect of -7.6 MM t).

Dairy herds fall by 4% on average for the EU-27. When taking absolute size of dairy herds into account, highest changes are projected to be in the Netherlands (-9%) and in Poland (-7%) . The main two drivers for these results are the high profitability of cattle systems (the standard puts a higher burden on high productive systems) and the composition of the cattle herd in the respective MS. For instance, the Netherlands has a much larger dairy herd than beef herd, and consequently production losses are higher for dairy cattle (compare respective Tables in the annex). Milk production follows the dairy cattle changes, with some slight extensification effects (less than 1% on average).

Beef cattle is the activity most hit by the emission standard. The reduction in herds are in the range of -26% for the EU-27 (-40% for Denmark, -38% for Spain and Ireland -36% as highest values).

Beef meat yields also contract by about -3% and beef production is projected to decrease by -15% (cf. respective Table in the annex).

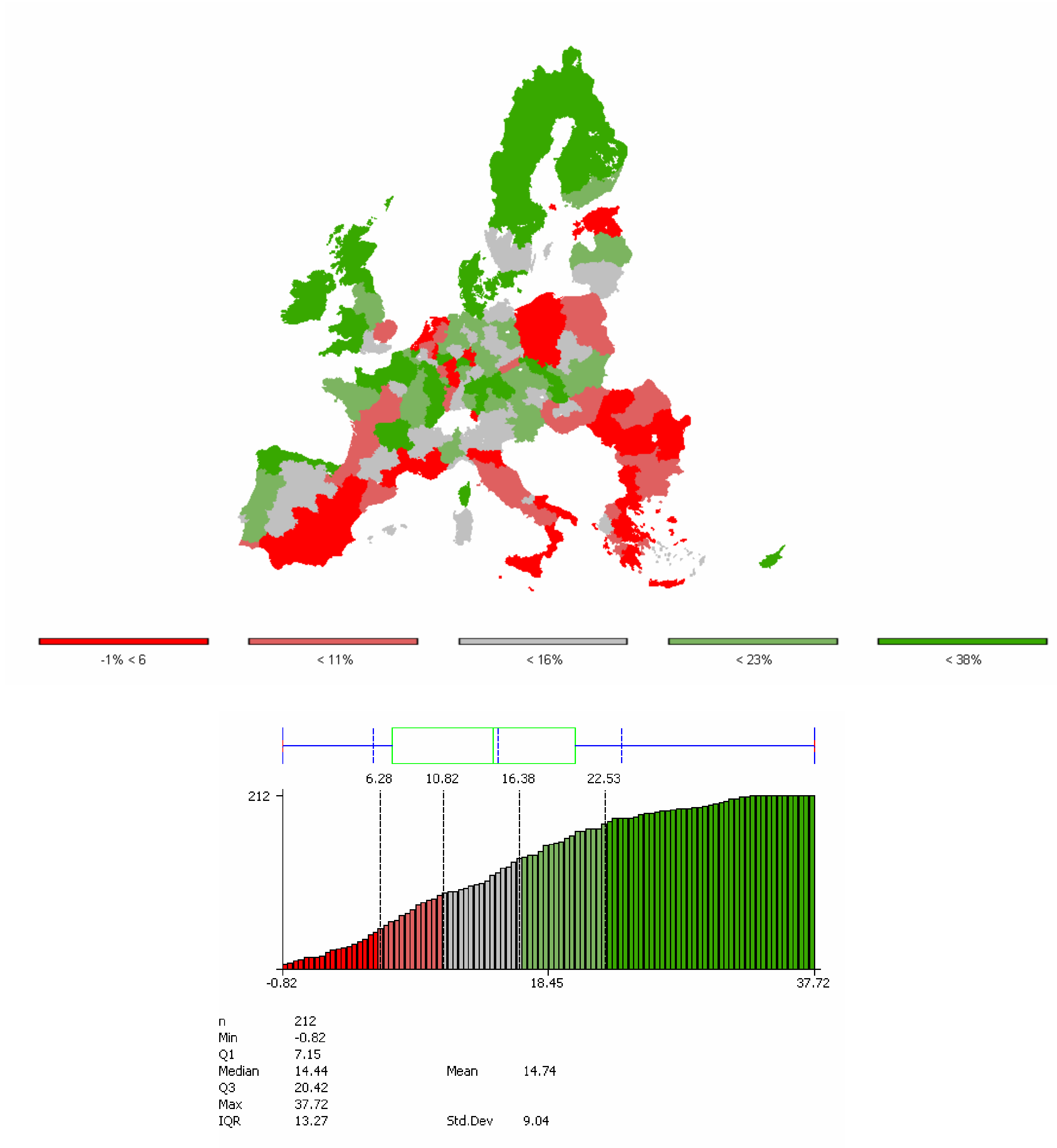

Figure 8.1: Change in agricultural income per utilised agricultural area according to the emission standard scenario (in %)

Following the quota effect, the agricultural sector increases its income by 14.7% on average due to higher production prices (left movement along the demand curve). As we can see in Figure 8.1, only few regions experience some income losses, mainly in the Eastern part and southern Spain.

This effect has clearly to do with the existence of 'hot air', i.e. those regions do not see their production pattern constrained by the emission standard because they experienced large reductions in production since 2004. It is important to note that some large effects, such as in Sweden and Finland, are affecting very low production numbers, so that even if the percentage effect is large, the overall effect on European agricultural income is fairly small.

8.4.1.3 Analysis of emission abatement costs

Figure 8.2 and its related distribution diagram highlights the large differences in marginal abatement costs across EU agriculture after the implementation of a -20% emission reduction target compared to the 2003-2005 base year. The high absolute levels of abatement cost in some Spanish regions, Belgium, the Netherlands and Ireland can hence be mostly attributed to the fact that emission levels in 2020 do not change (much) in the baseline compared to the base year 2004. Low levels in the EU12 can be attributed to already large baseline reductions compared to 2004 before introducing the emission 'cap'. Italy, Germany and France are example of regions with only moderate reductions compared to the 2004 levels, with sizeable differences at the regional level linked to different specialization. Generally, abatement costs are low where larger adjustments between 2004 and 2020 have taken place, such as e.g. the Massif Central in France with its extensive beef cattle production, whereas regions favourable and specialized on arable cropping as the Eastern part of England or parts of Germany, as well as regions with high organic nutrient loads such as Denmark, the Western parts of Germany or the Po flats in Northern Italy are characterized by rather high abatement costs. The distribution diagram also reveals that average marginal abatement costs in agriculture – at least given the limited mitigation offered by the model – are rather high compared to current prices in EU emission markets[20].

[20] Carbon prices in the ETS have varied between 0 and 30€ per ton of CO2eq in the first two phases since its implementation (between 2005 and 2009). These low prices have had to do with very moderate abatement efforts and over-supply of permits (see Ellermann and Buchner, 2007).

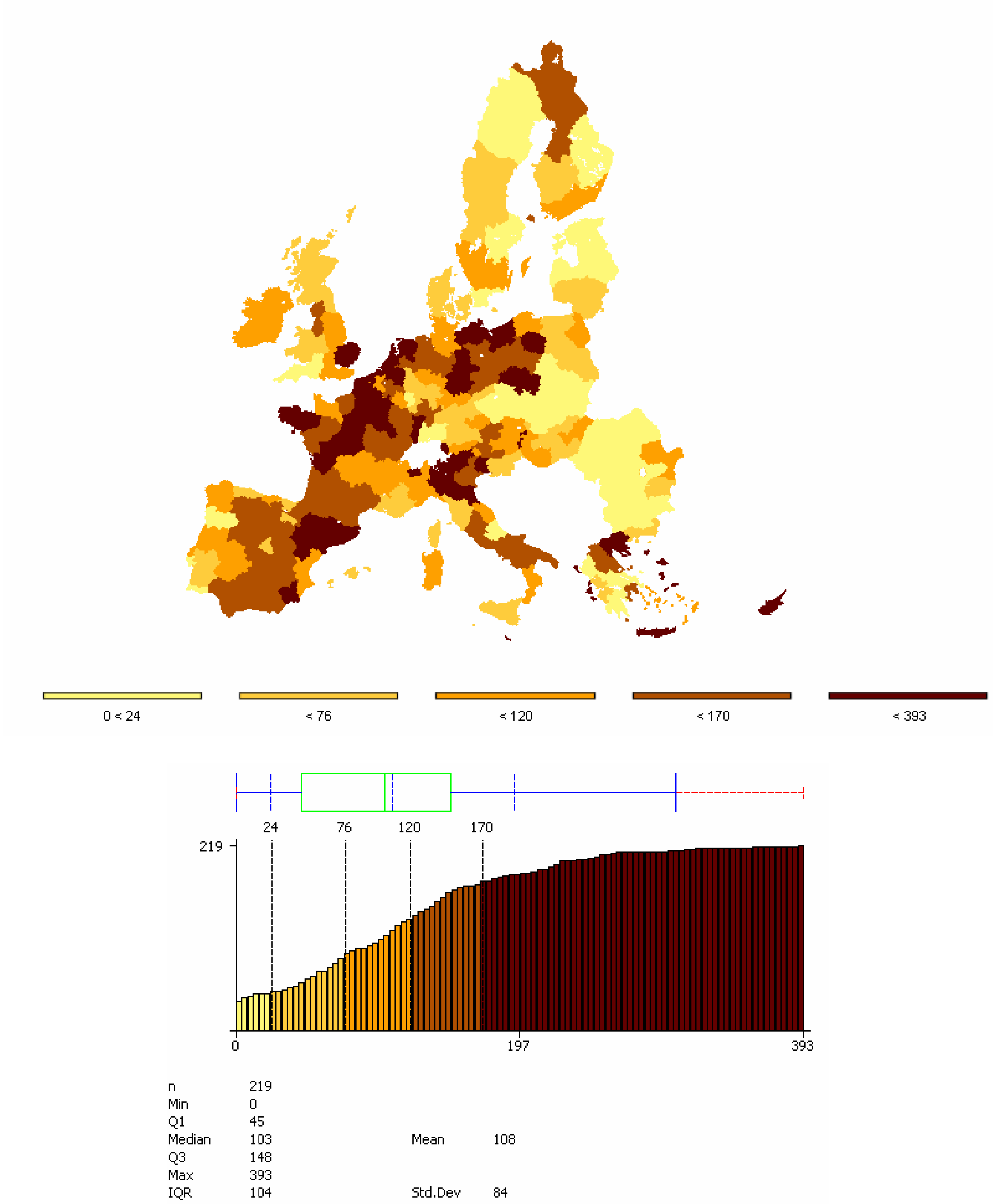

Figure 8.2: Marginal abatement costs with an emission standard (in thousand €/t $CO_{2\text{-}eq}$)

8.4.1.4 Analysis of environmental effects with regard to nitrogen balance

The introduction of an emission standard of 20% stimulates extensification effects in agriculture. In Figure 8.3 the yield changes for extensive fodder production and beef production are depicted. On average for the EU-27 fodder activities (mostly fodder maize and intensive grazing) reduce their yields by -12%. Beef meat activities also reduce yields by -3% on average. This lowering of yields mitigates a bit the negative effect on acreages and herd sizes.

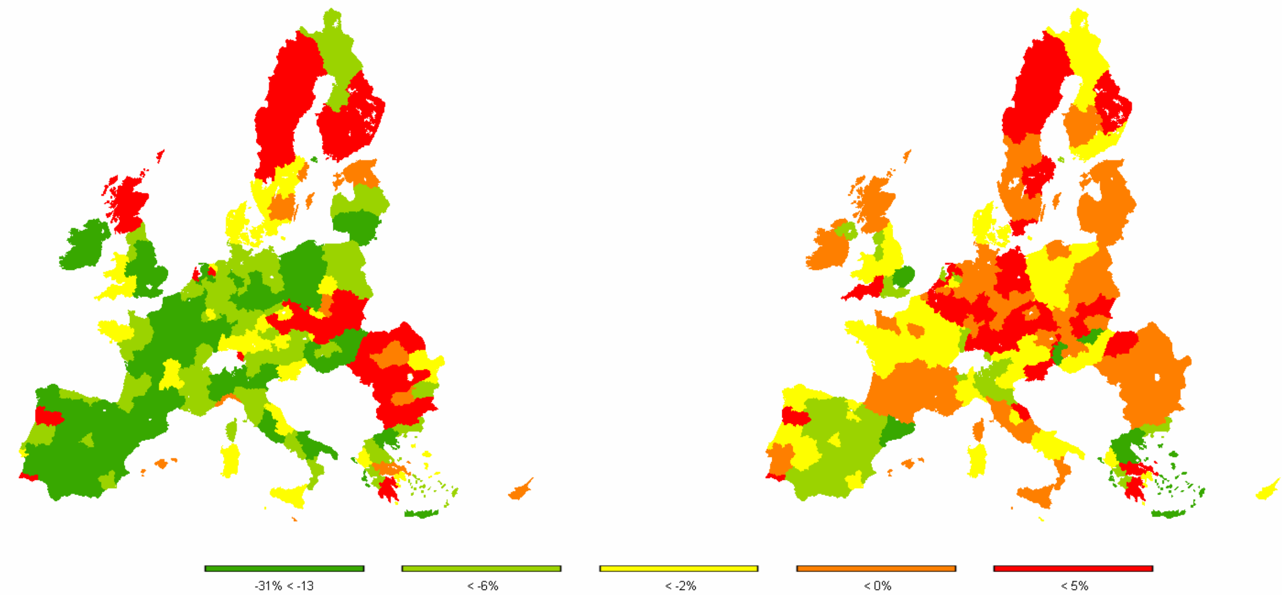

Figure 8.3: Yield changes in fodder (left) and beef activities (right) according to the emission standard scenario

With the emission standard, nitrogen surplus is reduced in the EU-27 by -17.5%. Since the reduction in emissions between the baseline and the base year is -13.7% (see Table below), this implies a more than proportional reduction in nitrogen surplus. This has to do with large extensification effects in arable crops (most savings come in “import of nitrogen by mineral fertilizer application” i.e. nitrogen applied to the crop coming from mineral fertilizer)

Table 8.20: Changes in the nitrogen balance according to the emission standard scenario

		Baseline year (REF, 2020)				Emission Standard (STD, 2020)			
		EU15 [1000 t N]	EU10 [1000 t N]	BUR [1000 t N]	EU27 [1000 t N]	EU15 *[% to REF]*	EU10 *[% to REF]*	BUR *[% to REF]*	EU27 *[% to REF]*
Import by mineral fertilizer	(+)	10915	8844	2070	11227	-17,2%	-18,8%	-10,3%	-16,6%
Import by manure	(+)	8782	7780	1001	9177	-11,2%	-12,0%	-5,0%	-10,7%
Import by crop residues	(+)	5674	4812	862	6204	-16,3%	-17,2%	-11,3%	-14,9%
Biological fixation	(+)	971	894	77	1036	-18,2%	-19,2%	-6,2%	-17,2%
Atmospheric deposition	(+)	1983	1659	324	2174	-6,4%	-6,9%	-3,8%	-5,8%
Nutrient retention by crops	(-)	17467	14760	2707	18755	-14,2%	-15,2%	-9,0%	-13,2%
Surplus total	(=)	10856	9229	1628	11063	-14,8%	-15,9%	-8,3%	-14,5%
Gaseous loss	(-)	3714	3141	573	3868	-10,8%	-11,6%	-6,3%	-10,3%
Run off mineral	(-)	376	261	115	403	-15,1%	-18,2%	-7,9%	-14,0%
Run off manure	(-)	413	342	71	449	-9,8%	-11,0%	-4,3%	-9,1%
Surplus at soil level	(=)	6354	5484	869	6344	-17,4%	-18,5%	-9,9%	-17,5%

8.4.2. Effort Sharing Agreement in Agriculture (ESAA)

8.4.2.1 Changes in GHG emissions

For the analysis of the ESAA scenario is important to acknowledge the issue of “hot air”. This implies that reduction commitments of certain regions (as they get the reduction commitment of their respective MS) are not binding for the period 2004-2020, since the emission projections in the baseline for those entities are already lower than the commitment. This is the case in most EU12 MS, as presented in the column “Hot Air” of Table 8.21. The overall effect is a reduction in EU emissions (-20%, column 4 in Table 8.21) higher than what the commitment was aiming at (-16%, column 3 in Table 8.21). This is due to the fact that other constraints that have to do with agricultural production prevent those MS from fully using their emission possibilities. On the one side, the highest reductions (-27%) are imposed on Ireland, Netherlands and Spain. On the other side, several EU12 MS are not required to further reduce emissions under the ESAA scenario and are even allowed to increase their emissions (e.g. +13% for Bulgaria and +12% for Romania).

Table 8.21: Emission commitments and effective emission reductions under the effort sharing agreement in agriculture scenario

	ESD commitment	ESD + 6.64% commitment (ESAA)	ESD + 6.64% commitment (incl. hot air)	*Hot Air*
Austria	-16.0%	-22.6%	-23.2%	
Belgium+Luxembourg	-15.0%	-21.6%	-22.1%	
Bulgaria	20.0%	13.4%	-20.3%	33.7%
Cyprus	-5.0%	-11.6%	-12.1%	
Czech Republic	9.0%	2.4%	-23.4%	25.8%
Denmark	-20.0%	-26.6%	-27.1%	
Estonia	11.0%	4.4%	-15.2%	19.6%
Finland	-16.0%	-22.6%	-23.1%	
France	-14.0%	-20.6%	-21.1%	
Germany	-14.0%	-20.6%	-21.1%	
Greece	-4.0%	-10.6%	-12.1%	1.5%
Hungary	10.0%	3.4%	-7.1%	10.5%
Ireland	-20.0%	-26.6%	-27.1%	
Italy	-13.0%	-19.6%	-20.2%	
Latvia	17.0%	10.4%	-15.7%	26.1%
Lithuania	15.0%	8.4%	-8.9%	17.3%
Malta	5.0%	-1.6%	-2.1%	
Netherlands	-16.0%	-22.6%	-23.2%	
Poland	14.0%	7.4%	-9.1%	16.5%
Portugal	1.0%	-5.6%	-9.6%	3.9%
Romania	19.0%	12.4%	-19.8%	32.2%
Slovakia	13.0%	6.4%	-23.5%	29.9%
Slovenia	4.0%	-2.6%	-5.9%	3.3%
Spain	-10.0%	-16.6%	-17.1%	
Sweden	-17.0%	-23.6%	-24.1%	
United Kingdom	-16.0%	-22.6%	-23.2%	
EU27	-9.1%	-15.7%	-20.0%	

Table 8.22 presents projections of percentage changes of GHG and ammonia emissions in 2020 under the ESAA scenario compared to the emissions in the baseline. As the modelled policy aimed

at a -20% reduction of GHG emissions in the EU-27, the EU-27 reduces emission CO_2 equi. by a further -13.2% in addition to the already achieved -6.8 % in the baseline. We observe that the EU15 considerably reduces emissions of CO_{2-eq} and ammonia, -16.1% and -10.2% respectively compared to the reference scenario. The highest reductions are projected in Ireland, Netherlands and Spain (i.e. the MS with the largest commitments). On the contrary, the EU10 and Bulgaria/Romania do not fully exploit their extra emission allowances but are projected to increase methane emissions by 4.9% and 0.7% respectively.

Table 8.22: Emissions per Member State according to the effort sharing agreement in agriculture scenario

	Baseline (REF, 2020)				Effort sharing agreement agriculture (ESAA, 2020)			
	Methane [t]	Nitrous Oxide [t]	CO2 equivalents [t]	Ammonia [t]	Methane [% to REF]	Nitrous Oxide [% to REF]	CO2 equivalents [% to REF]	Ammonia [% to REF]
Austria	171.8	12.5	7472.7	47.2	-16.7	-13.7	-15.2	-11.0
Belgium-Lux.	251.1	18.2	10915.8	73.6	-18.1	-18.5	-18.3	-13.9
Denmark	200.1	19.6	10287.4	92.2	-13.2	-10.5	-11.6	-7.8
Finland	81.6	23.8	9103.2	20.3	-8.8	-19.5	-17.4	-6.3
France	1526.0	152.8	79412.4	495.7	-15.9	-17.0	-16.6	-11.3
Germany	1210.5	115.7	61275.5	504.5	-9.7	-15.8	-13.2	-6.1
Greece	144.8	9.0	5814.9	28.5	-0.3	0.0	-0.1	1.2
Ireland	527.7	39.3	23276.5	106.4	-27.2	-25.3	-26.2	-25.5
Italy	791.3	52.2	32800.9	322.9	-13.8	-14.6	-14.2	-10.5
Netherlands	442.2	33.3	19609.2	100.8	-18.7	-24.2	-21.6	-21.8
Portugal	148.4	9.3	6005.9	46.6	4.4	1.8	3.2	4.5
Spain	894.8	72.2	41171.3	319.3	-19.1	-19.4	-19.2	-11.7
Sweden	124.5	20.0	8811.7	44.3	-7.0	-12.7	-11.0	-3.9
United Kingdom	919.5	121.2	56876.3	224.5	-11.1	-18.2	-15.8	-7.1
EU15	7434.2	699.1	372833.6	2426.5	-14.5	-17.2	-16.1	-10.2
Cyprus	12.6	0.8	496.2	5.4	-10.5	-8.0	-9.0	-7.4
Czech Republic	62.9	13.1	5393.2	50.9	5.1	1.8	2.6	3.2
Estonia	13.8	2.4	1018.2	5.7	1.0	3.8	3.0	0.5
Hungary	56.3	19.1	7099.3	62.8	2.6	2.1	2.2	3.1
Latvia	21.4	4.6	1876.9	10.2	2.3	2.8	2.6	2.8
Lithuania	55.3	10.5	4399.9	24.2	2.0	0.9	1.2	2.7
Malta	2.2	0.2	95.5	1.2	-8.7	-6.3	-8.1	-6.9
Poland	387.1	68.7	29419.2	258.4	5.9	1.8	2.9	3.3
Slovac Republic	26.2	4.5	1928.8	13.7	6.1	0.9	2.5	3.2
Slovenia	36.2	2.7	1604.0	12.0	9.7	3.3	6.3	5.4
10 New MS	673.9	126.4	53331.1	444.5	4.9	1.7	2.6	3.1
Bulgaria	69.4	7.9	3910.0	21.6	1.2	0.6	0.8	1.9
Romania	289.2	23.7	13432.2	91.3	0.5	0.7	0.6	1.7
Bulgaria/Romania	358.7	31.7	17342.2	112.9	0.7	0.7	0.7	1.7
EU27	8466.8	857.1	443506.9	2984.0	-12.3	-13.7	-13.2	-7.7

We observe in the following table the reductions in methane emissions mainly come from enteric fermentation in the EU15. Regarding the reduction of nitrous oxide emissions in the EU-27, the indirect nitrous oxide emissions from leaching are - in relative terms - reduced most. Taking absolute terms into account a major component of the additional -13.7% reduction of nitrous oxide

emissions achieved in the EU-27 compared to REF stem from the -19.8% reduction of emissions from anorganic fertilizer application in EU15.

Table 8.23: Change in emissions per inventory position for the EU according to the effort sharing agreement in agriculture scenario

	Baseline (REF, 2020)				Effort sharing agreement agric. (ESAA, 2020)			
	EU15	EU10	BUR	EU27	EU15	EU10	BUR	EU27
	[1000t]	[1000t]	[1000t]	[1000t]	[% to REF]	[% to REF]	[% to REF]	[% to REF]
Methane emissions from enteric fermentation (IPCC)	6002.4	555.7	328.6	6886.6	-15.7	5.0	0.6	-13.2
Methane emissions from manure management (IPCC)	1431.8	118.2	30.1	1580.1	-9.6	4.1	1.5	-8.4
Methane emissions	7434.2	673.9	358.7	8466.8	-14.5	4.9	0.7	-12.3
Direct nitrous oxide emissions stemming from manure managment and application except grazings (IPCC)	173.8	31.4	8.0	213.2	-12.0	3.9	1.3	-9.2
Direct nitrous oxide emissions stemming from manure management (only housing and storage) (IPCC)	*103.2*	*20.7*	*5.8*	*129.6*	*-13.2*	*4.0*	*1.0*	*-9.8*
Direct nitrous oxide emissions stemming from manure application on soils except grazings (IPCC)	*70.6*	*10.7*	*2.2*	*83.5*	*-10.2*	*3.6*	*1.4*	*-8.2*
Direct nitrous oxide emissions from anorganic fertilizer application (IPCC)	183.8	42.5	6.4	232.7	-19.8	3.9	3.8	-14.8
Direct nitrous oxide emissions from crop residues (IPCC)	73.9	12.2	7.5	93.6	-18.2	1.8	1.6	-14.0
Direct nitrous oxide emissions from nitrogen fixing crops (IPCC)	12.2	1.1	0.7	14.0	-20.8	-7.3	1.4	-18.6
Direct nitrous oxide emissions from atmosferic deposition (IPCC)	15.0	2.9	1.9	19.8	-9.3	0.0	0.0	-7.0
Indirect nitrous oxide emissions from ammonia volatilisation (IPCC)	41.9	7.6	2.0	51.5	-11.9	3.2	1.5	-9.1
Indirect nitrous oxide emissions from leaching (IPCC via Miterra)	15.1	3.6	0.7	19.4	-32.9	-36.2	-45.1	-34.0
Direct nitrous oxide emissions from cultivation of histosols (IPCC via Miterra)	108.8	20.7	0.2	129.7	-18.8	0.4	0.0	-15.7
Nitrous oxide emissions	699.1	126.4	31.7	857.1	-17.2	1.7	0.7	-13.7
Carbon dioxide equivalent emissions (global warming potential)	372833.6	53331.1	17342.2	443506.9	-16.1	2.6	0.7	-13.2
Ammonia emissions	2426.5	444.5	112.9	2984.0	-10.2	3.1	1.7	-7.7

8.4.2.2 Analysis of economic effects

The economic and production effects of the ESAA are of similar nature than the ones projected and described in the STD scenario. However, as emission reduction commitments are less binding in EU12, distribution of economic and income effects is different in ESAA than in the STD scenario. For instance, the production effects in countries like the Netherlands, Denmark or Ireland are more important. Especially beef meat activities in EU15 are affected, with beef herd reductions of -54% in Denmark and -47% in Ireland. The opposite is observed for EU10 and BUR, where the effects are somewhat reversed, and all MS show beef herd increases. The projection show, that the decrease in beef meat activity in the EU15 on the one hand, and its increase in the EU12 on the

other hand, results in a similar overall reduction of herd size (-25%) and production (-14%) in the EU-27 as projected in the STD scenario (with herd size -26% and production -15%) Further details on the main market balances for cereals, dairy and beef meat activities are given in the annex to this chapter. Utilised agricultural area is expected to decrease by -5% and fallow land increases by 5%.

Table 8.24: Change in income, area, yield and supply for the EU-27 for activity aggregates according to the effort sharing agreement in agriculture scenario

	Baseline (REF, 2020)				Effort sharing agreement agric. (ESAA, 2020)			
	Income	Area/ Herd sizes	Yield	Supply	Income	Area/ Herd sizes	Yield	Supply
	[Eur ha or hd]	[1000 ha or hd]	[kg/ha or hd]	[1000 t]	*[% to REF]*	*[% to REF]*	*[% to REF]*	*[% to REF]*
Cereals	550	56737	5750	326227	17.5%	-4.9%	-0.3%	-5.2%
Oilseeds	328	10034	2917	29266	23.6%	-4.7%	-1.2%	-5.8%
Other arable crops	864	8185	19874	162678	22.5%	-4.8%	-8.2%	-12.6%
Vegetables and Permanent crops	6131	15092	11525	173932	1.0%	0.3%	-0.2%	0.1%
Fodder activities	274	80976	23060	1867313	1.4%	-8.4%	-12.1%	-19.4%
Set aside and fallow land	135	14976			7.1%	5.3%		
Utilized agricultural area	1287	187450	13656	2559779	17.7%	-5.1%	-11.2%	-15.7%
All cattle activities	461	84745	93	7907	66.1%	-16.0%	2.4%	-14.0%
Beef meat activities	152	27015	362	9785	172.8%	-25.2%	-3.7%	-28.0%
Other animals	110	394741	776	306251	24.4%	-6.0%	2.5%	-3.6%

Income effects in the ESAA scenario are similar on average to the STD scenario (+14%) but differently distributed (cf. Figure 8.4).

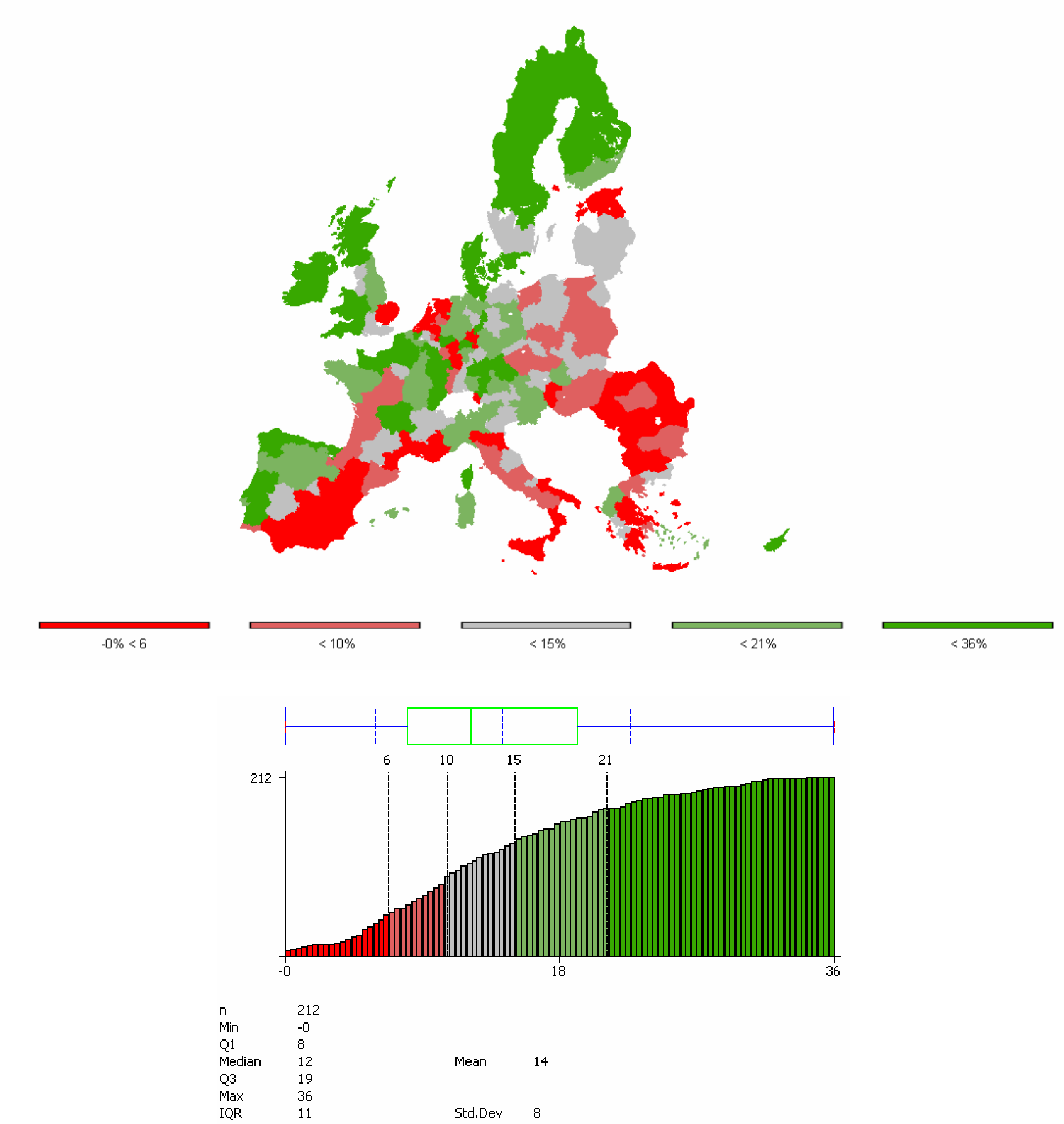

Figure 8.4: Change in agricultural income per utilised agricultural area according to the effort sharing agreement in agriculture scenario (in %)

8.4.2.3 Analysis of environmental effects with regard to nitrogen balance

In the Table below we observe that the surplus of nitrogen is expected to be reduced by -13.5% in 2020 under the ESAA scenario compared to the reference in 2020. This reduction is caused by the reduction of -16.7% expected in the EU15, while in the EU10 the surplus of nitrogen would be increased by +3% and in Bulgaria & Romania the surplus is expected to remain as in the reference scenario. The increase of the surplus of nitrogen in the EU10 under the ESSA scenario can be

explained by the increases in production, accompanied by some slight intensification in the cattle sector.

Table 8.25: Changes in the nitrogen balance according to the effort sharing agreement in agriculture scenario

		Baseline year (REF, 2020)				Effort sharing agreement agric. (ESAA, 2020)			
		EU15 [1000 t N]	EU10 [1000 t N]	BUR [1000 t N]	EU27 [1000 t N]	EU15 *[% to REF]*	EU10 *[% to REF]*	BUR *[% to REF]*	EU27 *[% to REF]*
Import by mineral fertilizer	(+)	8844	2070	312	11227	-19,8%	3,9%	3,7%	-14,8%
Import by manure	(+)	7780	1001	395	9177	-12,7%	3,3%	1,1%	-10,4%
Import by crop residues	(+)	4812	862	530	6204	-18,1%	1,8%	1,6%	-13,7%
Biological fixation	(+)	894	77	66	1036	-19,8%	-8,1%	1,4%	-17,6%
Atmospheric deposition	(+)	1659	324	191	2174	-7,7%	0,5%	0,6%	-5,7%
Nutrient retention by crops	(-)	14760	2707	1288	18755	-16,1%	2,8%	2,1%	-12,1%
Surplus total	(=)	9229	1628	207	11063	-16,7%	3,0%	-0,1%	-13,5%
Gaseous loss	(-)	3141	573	154	3868	-12,2%	3,3%	1,7%	-9,4%
Run off mineral	(-)	261	115	27	403	-19,2%	4,3%	4,0%	-11,0%
Run off manure	(-)	342	71	36	449	-11,5%	3,4%	1,2%	-8,1%
Surplus at soil level	(=)	5484	869	-10	6344	-19,4%	2,6%	-45,5%	-16,5%

8.4.3. Emission trading scheme for agriculture (ETSA)

Emission trading belongs to the family of market-based instruments for emission mitigation. These instruments use market signals in the form of a modification of relative prices to influence behaviour and reward environmental performance through the market. By doing this, a higher economic efficiency compared to command and control mechanisms should be achieved since polluters are allowed to vary their pollution level according to their marginal costs of abatement. Nevertheless, some problems linked to the application of these instruments might arise. Firstly it is not easy for policy makers to justify the case that environmental performance can be achieved through eventually higher levels of pollution from specific sites (political problem) and, moreover, an in-equitable redistribution of the abatement effort could take place since some producers might have a much more efficient production structure than others and would be therefore less affected economically by these instruments (targeting problem).

8.4.3.1 Changes in GHG emissions

In Table 8.26 the emission reduction results of the ETSA scenario is compared to the previous two scenarios (ESAA and STD). A reallocation of emissions from the EU10 to the EU15 is observed, which corresponds to the market signals given to producers based on the costs of emission abatement they face.

Table 8.26: Emission commitments and emission reductions under the emission trading scheme for agriculture scenario compared to the emission standard and emission sharing agreement scenarios

	BAS [1000 t]	REF [1000 t]	STD vs BAS [%]	REF vs BAS [%]	ESAA vs REF [%]	ETSA vs REF [%]
Austria	8158	7473	-20.0	-8.4	-15.2	-8.5
Belgium-Lux.	11153	10916	-20.0	-2.1	-18.3	-9.1
Denmark	12225	10287	-20.0	-15.8	-11.6	-7.4
Finland	9703	9103	-20.0	-6.2	-17.4	-23.5
France	82776	79412	-20.0	-4.1	-16.6	-8.2
Germany	66586	61276	-20.0	-8.0	-13.2	-9.6
Greece	6548	5815	-20.6	-11.2	-0.1	-7.5
Ireland	23300	23277	-20.0	-0.1	-26.2	-19.5
Italy	34759	32801	-20.0	-5.6	-14.2	-6.8
Netherlands	19604	19609	-20.0	0.0	-21.6	-6.6
Portugal	6813	6006	-22.0	-11.9	3.2	-15.5
Spain	39502	41171	-20.0	4.2	-19.2	-13.9
Sweden	10247	8812	-20.1	-14.0	-11.0	-14.0
United Kingdom	61387	56876	-20.0	-7.3	-15.8	-31.6
EU15	392761	372834	-20.1	-5.1	-16.1	-13.8
Cyprus	503	496	-20.0	-1.4	-9.0	-10.8
Czech Republic	7279	5393	-29.3	-25.9	2.6	-13.0
Estonia	1237	1018	-20.0	-17.7	3.0	-17.4
Hungary	7841	7099	-20.0	-9.5	2.2	-10.2
Latvia	2234	1877	-20.0	-16.0	2.6	-20.6
Lithuania	4842	4400	-20.0	-9.1	1.2	-15.6
Malta	88	95	-20.0	8.6	-8.1	-11.5
Poland	33052	29419	-22.1	-11.0	2.9	-11.3
Slovac Republic	2586	1929	-27.2	-25.4	2.5	-4.8
Slovenia	1827	1604	-20.0	-12.2	6.3	-12.5
10 New MS	61489	53331	-22.5	-13.3	2.6	-11.9
Bulgaria	5002	3910	-23.5	-21.8	0.8	-11.8
Romania	16839	13432	-21.8	-20.2	0.6	-10.4
Bulgaria/Romania	21841	17342	-22.2	-20.6	0.7	-10.7
EU27	476090	443507	-20.5	-6.8	-13.2	-13.4

In Table 8.27 projected changes of GHG and ammonia emissions in 2020 under the ETSA scenario compared with the reference scenario in 2020 are presented. These projections show that unlike in the ESAA scenario where EU12 does not reduce emissions, here EU10 and Bulgaria/Romania are projected to reduce GHG emissions of $CO_{2\text{-eq}}$ by 11.9% and 10.7% respectively, after selling emission allowances to several EU15 MS. The EU15 is projected to reduce GHG emissions of $CO_{2\text{-eq}}$ by 13.8% in the ETSA scenario compared to the reference, i.e. 2.3% less emission reduction than in the ESAA scenario. The projections of ammonia emissions present a similar picture.

Table 8.27: Emissions per Member State according to emission trading scheme for agriculture scenario

	Baseline (REF, 2020)				Emission trading scheme agriculture (ETSA, 2020)			
	Methane [t]	Nitrous Oxide [t]	CO2 equivalents [t]	Ammonia [t]	Methane [% to REF]	Nitrous Oxide [% to REF]	CO2 equivalents [% to REF]	Ammonia [% to REF]
Austria	171.8	12.5	7472.7	47.2	-9.2	-7.8	-8.5	-6.3
Belgium-Lux.	251.1	18.2	10915.8	73.6	-8.4	-9.8	-9.1	-6.0
Denmark	200.1	19.6	10287.4	92.2	-8.4	-6.7	-7.4	-5.0
Finland	81.6	23.8	9103.2	20.3	-11.1	-26.4	-23.5	-9.2
France	1526.0	152.8	79412.4	495.7	-6.7	-9.2	-8.2	-4.9
Germany	1210.5	115.7	61275.5	504.5	-7.8	-11.0	-9.6	-5.1
Greece	144.8	9.0	5814.9	28.5	-7.3	-7.6	-7.5	-5.7
Ireland	527.7	39.3	23276.5	106.4	-20.4	-18.6	-19.5	-19.2
Italy	791.3	52.2	32800.9	322.9	-5.8	-7.8	-6.8	-4.5
Netherlands	442.2	33.3	19609.2	100.8	-5.1	-7.9	-6.6	-6.5
Portugal	148.4	9.3	6005.9	46.6	-12.9	-18.2	-15.5	-9.1
Spain	894.8	72.2	41171.3	319.3	-12.7	-14.9	-13.9	-8.1
Sweden	124.5	20.0	8811.7	44.3	-8.5	-16.4	-14.0	-5.6
United Kingdom	919.5	121.2	56876.3	224.5	-19.5	-37.8	-31.6	-12.3
EU15	7434.2	699.1	372833.6	2426.5	-10.3	-16.2	-13.8	-6.9
Cyprus	12.6	0.8	496.2	5.4	-12.9	-9.3	-10.8	-9.6
Czech Republic	62.9	13.1	5393.2	50.9	-11.3	-13.6	-13.0	-6.3
Estonia	13.8	2.4	1018.2	5.7	-19.4	-16.6	-17.4	-17.5
Hungary	56.3	19.1	7099.3	62.8	-8.2	-10.6	-10.2	-4.0
Latvia	21.4	4.6	1876.9	10.2	-15.3	-22.2	-20.6	-15.0
Lithuania	55.3	10.5	4399.9	24.2	-9.0	-18.0	-15.6	-9.3
Malta	2.2	0.2	95.5	1.2	-12.4	-12.5	-11.5	-12.1
Poland	387.1	68.7	29419.2	258.4	-11.7	-11.1	-11.3	-7.7
Slovac Republic	26.2	4.5	1928.8	13.7	-2.6	-5.8	-4.8	-1.8
Slovenia	36.2	2.7	1604.0	12.0	-13.4	-11.8	-12.5	-10.3
10 New MS	673.9	126.4	53331.1	444.5	-11.2	-12.2	-11.9	-7.3
Bulgaria	69.4	7.9	3910.0	21.6	-10.1	-12.8	-11.8	-8.9
Romania	289.2	23.7	13432.2	91.3	-11.5	-9.4	-10.4	-7.3
Bulgaria/Romania	358.7	31.7	17342.2	112.9	-11.2	-10.3	-10.7	-7.6
EU27	8466.8	857.1	443506.9	2984.0	-10.4	-15.4	-13.4	-7.0

Similar as in the results of the ESAA scenario the major reductions of methane emissions are projected in the emissions coming from the enteric fermentation. The indirect nitrous oxide emissions from leaching and the direct nitrous oxide emissions from cultivation of histosols account for the major reductions of nitrous oxide emissions. Significant potential for further emission reductions compared to the reference are projected by the direct nitrous oxide emissions from anorganic fertilizer and from crop residues. These components were responsible for emission increases in the ESAA scenario compared to the reference in the EU10 and Bulgaria/Romania.

Table 8.28: Change in emissions per inventory position for the EU according to the emission trading scheme for agriculture scenario

	Baseline (REF, 2020)				Emission trading scheme agriculture (ETSA, 2020)			
	EU15	EU10	BUR	EU27	EU15	EU10	BUR	EU27
	[1000t]	[1000t]	[1000t]	[1000t]	[% to REF]	[% to REF]	[% to REF]	[% to REF]
Methane emissions from enteric fermentation (IPCC)	6002.4	555.7	328.6	6886.6	-11.4	-11.9	-11.4	-11.4
Methane emissions from manure management (IPCC)	1431.8	118.2	30.1	1580.1	-6.0	-7.8	-8.7	-6.2
Methane emissions	7434.2	673.9	358.7	8466.8	-10.3	-11.2	-11.2	-10.4
Direct nitrous oxide emissions stemming from manure managment and application except grazings (IPCC)	173.8	31.4	8.0	213.2	-8.3	-8.1	-9.1	-8.4
Direct nitrous oxide emissions stemming from manure management (only housing and storage) (IPCC)	*103.2*	*20.7*	*5.8*	*129.6*	*-9.7*	*-8.7*	*-9.5*	*-9.5*
Direct nitrous oxide emissions stemming from manure application on soils except grazings (IPCC)	*70.6*	*10.7*	*2.2*	*83.5*	*-6.5*	*-7.0*	*-9.0*	*-6.6*
Direct nitrous oxide emissions from anorganic fertilizer application (IPCC)	183.8	42.5	6.4	232.7	-15.7	-15.2	-8.3	-15.4
Direct nitrous oxide emissions from crop residues (IPCC)	73.9	12.2	7.5	93.6	-15.1	-15.2	-10.3	-14.7
Direct nitrous oxide emissions from nitrogen fixing crops (IPCC)	12.2	1.1	0.7	14.0	-15.4	-11.0	-14.1	-15.0
Direct nitrous oxide emissions from atmosferic deposition (IPCC)	15.0	2.9	1.9	19.8	-7.5	-5.1	-3.7	-6.7
Indirect nitrous oxide emissions from ammonia volatilisation (IPCC)	41.9	7.6	2.0	51.5	-8.2	-8.9	-8.4	-8.3
Indirect nitrous oxide emissions from leaching (IPCC via Miterra)	15.1	3.6	0.7	19.4	-31.1	-45.7	-52.1	-34.6
Direct nitrous oxide emissions from cultivation of histosols (IPCC via Miterra)	108.8	20.7	0.2	129.7	-33.4	-7.1	-5.0	-29.2
Nitrous oxide emissions	699.1	126.4	31.7	857.1	-16.2	-12.2	-10.3	-15.4
Carbon dioxide equivalent emissions (global warming potential)	372833.6	53331.1	17342.2	443506.9	-13.8	-11.9	-10.7	-13.4
Ammonia emissions	2426.5	444.5	112.9	2984.0	-6.9	-7.3	-7.6	-7.0

8.4.3.2 Analysis of economic effects

The production effects of the ETSA vary with respect to the previous scenarios. The effects across activities are more homogeneous, being beef meat activities less affected and arable crops in turn more affected. Utilizable agricultural area is expected to decrease by -6% and fallow land increases by 12%.

Table 8.29: Change in income, area, yield and supply for the EU-27 for activity aggregates according to the emission trading scheme in agriculture scenario

	Baseline (REF, 2020)				Emission trading scheme ag. (ETSA, 2020)			
	Income	Area	Yield	Supply	Income	Area	Yield	Supply
	[Eur hd or ha]	[1000 ha]	[kg/ha or hd]	[1000 t]	*[% to REF]*	*[% to REF]*	*[% to REF]*	*[% to REF]*
Cereals	550	56737	5750	326227	17,8%	-6,5%	1,6%	-5,0%
Oilseeds	328	10034	2917	29266	26,5%	-6,5%	0,5%	-6,1%
Other arable crops	864	8185	19874	162678	21,1%	-4,0%	-8,4%	-12,1%
Vegetables and Permanent crops	6131	15092	11525	173932	0,8%	0,3%	-0,2%	0,1%
Fodder activities	274	80976	23060	1867313	4,2%	-10,8%	-11,3%	-20,9%
Set aside and fallow land	135	14976			3,5%	11,8%		
Utilized agricultural area	1287	187450	13656	2559779	17,3%	-6,2%	-11,2%	-16,7%
All cattle activities	461	84745	93	7907	58,0%	-13,4%	2,2%	-11,5%
Beef meat activities	152	27015	362	9785	165,3%	-21,0%	-2,4%	-22,8%
Other animals	110	394741	776	306251	18,7%	-5,7%	3,0%	-2,9%

Regarding beef meet activities in the EU-27, an overall reduction in herd size of -21% and -11% in production can be observed. While in the EU15 these reductions are again most pronounced (and in a similar range as in the STD scenario) in Denmark and Ireland, it is striking that the reductions in the Netherlands are only projected to be -5.8% for beef herd size and production. It is also noticeable that in the EU12 all MS (except Cyprus) show reductions in meat activities higher than in the STD scenario.

Table 8.30: Beef cattle herds and beef market balances per Member State according to emission trading scheme for agriculture scenario

	Reference year (2020)				Emission trading scheme ag. (ETSA, 2020)			
	Beef* herd [1000 hd]	Production [1000 t]	Demand [1000 t]	Net trade [1000 t]	*Beef* herd [% to REF]*	*Production [% to REF]*	*Demand [% to REF]*	Net trade [□ to REF]
Austria	544	180	126	54	-19,3%	-11,7%	-4,3%	-16
Belgium-Lux.	694	280	190	90	-17,6%	-9,5%	-4,0%	-19
Denmark	341	113	213	-101	-41,5%	-25,1%	-5,7%	-16
Finland	232	77	95	-17	-25,9%	-15,8%	-3,4%	-9
France	6405	1698	1621	77	-10,8%	-5,6%	-5,3%	-8
Germany	1698	955	565	390	-26,5%	-18,8%	-4,2%	-155
Greece	317	46	142	-96	-11,0%	4,1%	-13,5%	21
Ireland	2599	615	86	529	-34,8%	-20,2%	-10,6%	-115
Italy	2463	935	1279	-345	-7,9%	-4,0%	-6,7%	48
Netherlands	62	334	370	-36	-5,8%	-5,8%	-6,6%	5
Portugal	642	128	200	-72	-27,5%	-3,1%	-6,7%	10
Spain	4501	725	798	-74	-23,0%	-12,0%	-12,7%	14
Sweden	352	125	268	-143	-20,3%	-13,0%	-4,0%	-6
United Kingdom	3560	810	1370	-559	-34,1%	-18,2%	-7,7%	-42
EU15	24411	7021	7325	-304	-21,3%	-11,3%	-6,9%	-288
Cyprus	17	5	6	-1	7,3%	1,6%	-15,8%	1
Czech Republic	121	61	24	37	-39,1%	-17,4%	-36,0%	-2
Estonia	25	12	4	8	-55,9%	-36,0%	-41,1%	-3
Hungary	47	32	28	3	-15,5%	-2,1%	-46,5%	13
Latvia	63	20	21	-1	-19,0%	-15,7%	-20,3%	1
Lithuania	57	32	14	18	-18,1%	-7,6%	-17,1%	0
Malta	4	2	10	-8	-1,9%	-2,7%	-15,9%	1
Poland	859	365	216	149	-22,2%	-18,3%	-20,4%	-23
Slovac Republic	35	30	21	10	3,1%	4,8%	-49,3%	12
Slovenia	123	51	62	-11	-26,5%	-1,0%	-23,6%	14
10 New MS	1351	609	406	204	-23,1%	-14,2%	-25,0%	15
Bulgaria	225	58	68	-9	-13,0%	-8,6%	-18,9%	8
Romania	1028	218	215	3	-11,9%	-9,3%	-8,1%	-3
Bulgaria/Romania	1253	276	283	-7	-12,1%	-9,2%	-10,7%	5
EU27	27015	7907	8014	-107	-21,0%	-11,5%	-8,0%	-268

8.4.3.3 Analysis of emission market

The following figure shows purchases of emission permits in the EU. It can be observed that the EU15 is the main buyer of permits in the ETSA. On average, 26 MM tonnes of permits are traded in the market, under the prevailing assumptions on transaction costs.

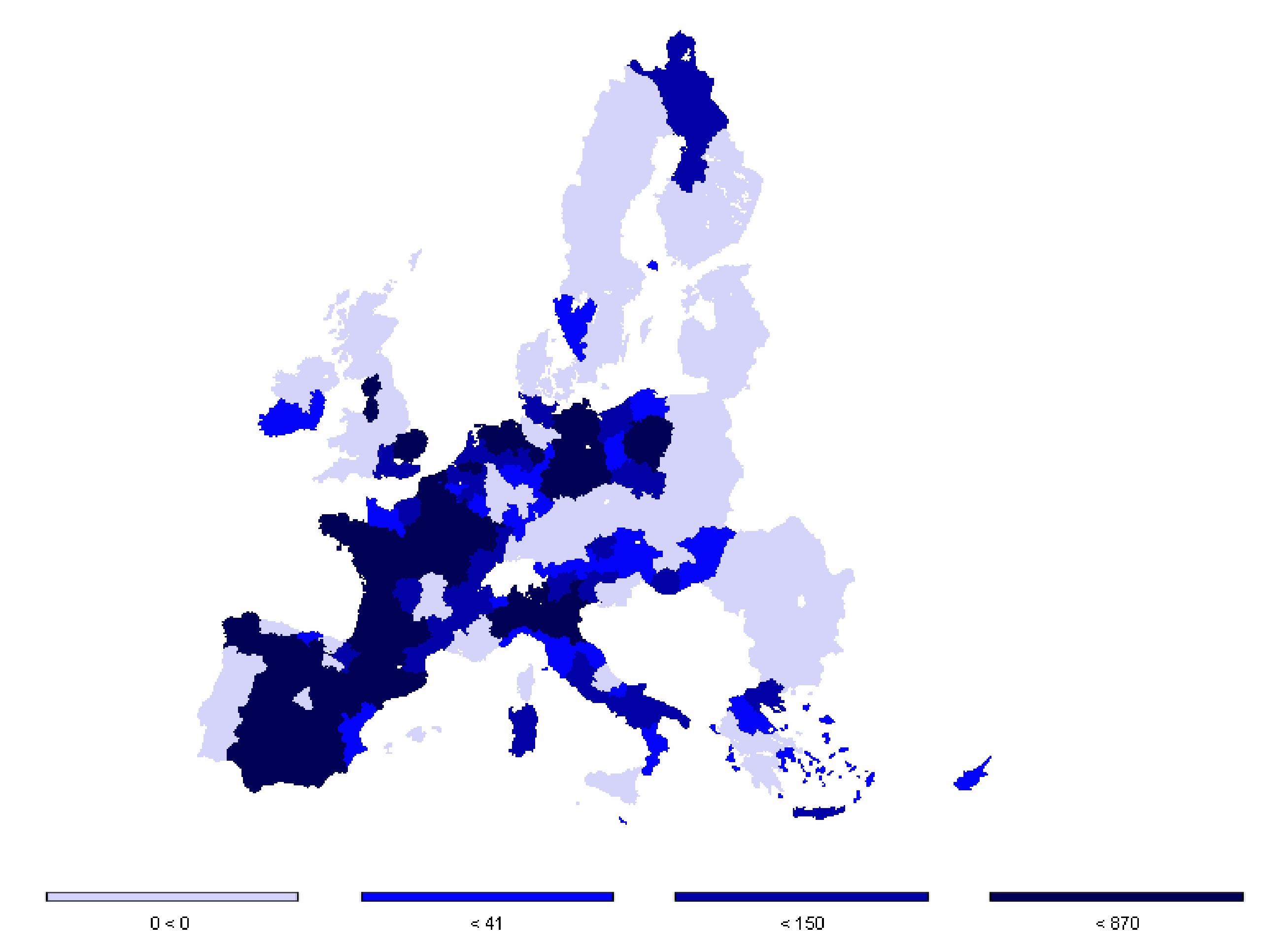

Figure 8.5: Purchases of emission permits in the emission trading scheme for agriculture scenario (in thousand)

In the following figure we can observe the differences in marginal abatement costs in the STD scenario (range from 0 to 368 Euro) and in the ETSA scenario with respect to the baseline. Differences in marginal abatement cost are only due to the presence of transaction costs (around 10€ per permit traded paid by the buyer).

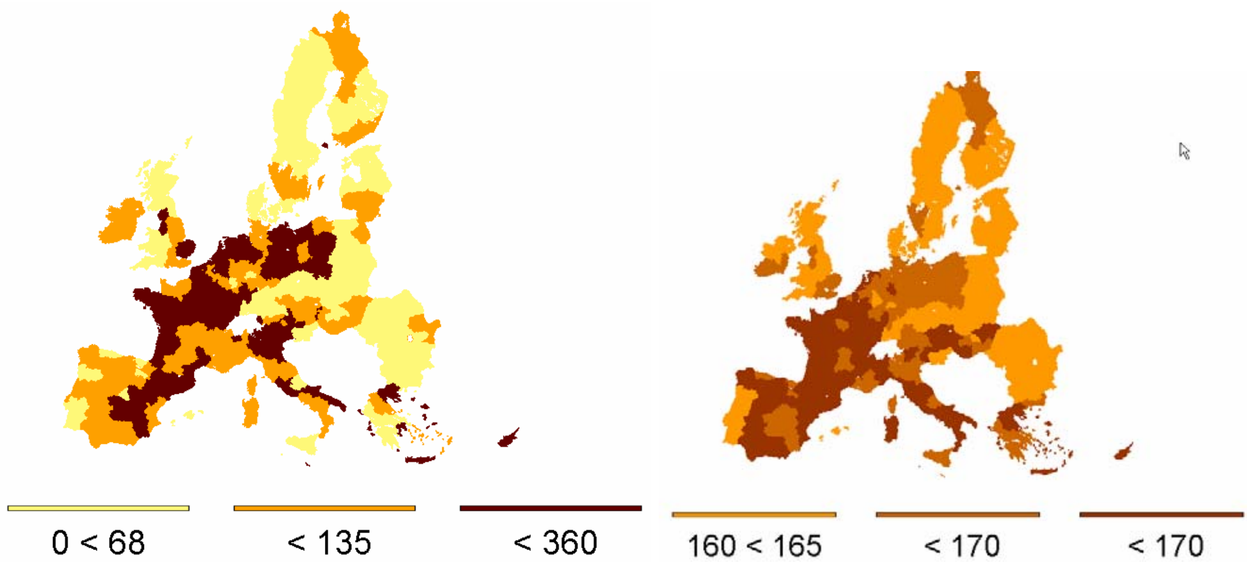

Figure 8.6: Differences in regional marginal abatement costs in the emission standard scenario (left) and the emission trading scenario (right)

8.4.3.4 Analysis of environmental effects with regard to nitrogen balance

The Table below presents data on the percentage changes of surplus of nitrogen in the ETSA scenario compared to the reference scenario. While the overall reduction in nitrogen surplus is -13% in the EU-27 and hence equal to the reduction in the ESAA scenario, it is noticeable that the reduction is projected to be the same -13% in EU15, EU10 and Bulgaria/Romania. This is different to the ESAA scenario, where the overall reduction in nitrogen surplus was projected to be achieved by an -17% decrease in EU15 and an increase of +3% in the EU10.

Table 8.31: Changes in the nitrogen balance according to the emission trading scheme in agriculture scenario

		Baseline year (REF, 2020)				Emission trading scheme ag. (ETSA, 2020)			
		EU15 [1000 t N]	EU10 [1000 t N]	BUR [1000 t N]	EU27 [1000 t N]	EU15 *[% to REF]*	EU10 *[% to REF]*	BUR *[% to REF]*	EU27 *[% to REF]*
Import by mineral fertilizer	(+)	8844	2070	312	11227	-15,7%	-15,2%	-8,2%	-15,4%
Import by manure	(+)	7780	1001	395	9177	-9,1%	-7,4%	-9,9%	-8,9%
Import by crop residues	(+)	4812	862	530	6204	-15,1%	-15,2%	-10,3%	-14,7%
Biological fixation	(+)	894	77	66	1036	-13,7%	-6,3%	-14,6%	-13,2%
Atmospheric deposition	(+)	1659	324	191	2174	-6,0%	-4,9%	-2,8%	-5,6%
Nutrient retention by crops	(-)	14760	2707	1288	18755	-12,4%	-12,4%	-8,3%	-12,2%
Surplus total	(=)	9229	1628	207	11063	-13,0%	-12,5%	-13,2%	-12,9%
Gaseous loss	(-)	3141	573	154	3868	-8,6%	-9,0%	-8,6%	-8,7%
Run off mineral	(-)	261	115	27	403	-16,2%	-15,2%	-9,4%	-15,5%
Run off manure	(-)	342	71	36	449	-8,7%	-7,4%	-9,7%	-8,6%
Surplus at soil level	(=)	5484	869	-10	6344	-15,7%	-14,9%	85,5%	-15,7%

8.4.4. Livestock emission tax (LTAX scenario)

For the scenario of an EU-wide livestock tax a simulation experiment was conducted, using different tax levels to approach a reduction of GHG emissions from the livestock sector in the EU by -20% compared to the base year. The overall decrease is a combination of the reduction when moving from the base year in 2004 to the baseline in 2020 (-6.8 %) and the reduction obtained from the analysed tax scenario of about -13.2%. This reduction of -20% could be obtained with a tax of around 300 € per ton of $CO_{2\text{-eq}}$ emissions for ruminant production activities and 164 € per ton of $CO_{2\text{-eq}}$ emissions for all non-ruminant animals.. The tax is split across the livestock types according to their emission intensities, including not only CH_4 but also N_2O from manure management activities.[21]

8.4.4.1 Changes in GHG emissions:

Differently than in the other scenarios, the burden of GHG emissions reduction falls on animal numbers. Thus in this scenario reductions in Methane emissions are generally bigger in almost all MS than in the other policy scenarios (see Table below).

[21] Emissions from manure management are included in the system. The calculations in CAPRI are performed at IPCC Tier 2 level, so that nutrient intake and excretion by animals, as well as intensity, is considered in the simulation.

Table 8.32: Change in emissions per Member State according to the livestock emission tax scenario

	Baseline (REF, 2020)				Carbon tax on livestock emissions (LTAX, 2020)			
	Methane [t]	Nitrous Oxide [t]	CO2 equivalents [t]	Ammonia [t]	Methane [% to REF]	Nitrous Oxide [% to REF]	CO2 equivalents [% to REF]	Ammonia [% to REF]
Austria	171,8	12,5	7472,7	47,2	-17,9	-11,0	-14,3	-10,7
Belgium-Lux.	251,1	18,2	10915,8	73,6	-14,7	-10,3	-12,4	-7,1
Denmark	200,1	19,6	10287,4	92,2	-17,3	-9,1	-12,5	-8,3
Finland	81,6	23,8	9103,2	20,3	-16,7	-2,3	-5,0	-8,5
France	1526,0	152,8	79412,4	495,7	-16,7	-7,4	-11,2	-8,3
Germany	1210,5	115,7	61275,5	504,5	-15,1	-5,1	-9,2	-6,2
Greece	144,8	9,0	5814,9	28,5	-16,4	-6,9	-11,8	-9,6
Ireland	527,7	39,3	23276,5	106,4	-25,4	-20,7	-23,0	-23,0
Italy	791,3	52,2	32800,9	322,9	-13,2	-8,6	-10,9	-7,9
Netherlands	442,2	33,3	19609,2	100,8	-8,9	-6,8	-7,8	-8,0
Portugal	148,4	9,3	6005,9	46,6	-25,5	-27,4	-26,4	-16,3
Spain	894,8	72,2	41171,3	319,3	-25,6	-14,5	-19,5	-10,8
Sweden	124,5	20,0	8811,7	44,3	-18,9	-6,8	-10,4	-10,5
United Kingdom	919,5	121,2	56876,3	224,5	-25,5	-14,5	-18,2	-11,6
EU15	7434,2	699,1	372833,6	2426,5	-18,6	-10,0	-13,6	-9,3
Cyprus	12,6	0,8	496,2	5,4	-6,1	-2,7	-4,3	0,2
Czech Republic	62,9	13,1	5393,2	50,9	-20,5	-5,9	-9,5	-5,2
Estonia	13,8	2,4	1018,2	5,7	-18,3	-10,2	-12,5	-2,1
Hungary	56,3	19,1	7099,3	62,8	-16,5	-3,8	-5,9	-3,9
Latvia	21,4	4,6	1876,9	10,2	-19,6	-11,1	-13,2	-11,3
Lithuania	55,3	10,5	4399,9	24,2	-17,0	-5,1	-8,2	-7,7
Malta	2,2	0,2	95,5	1,2	-7,3	-6,3	-6,5	-1,7
Poland	387,1	68,7	29419,2	258,4	-20,4	-6,1	-10,0	-7,2
Slovac Republic	26,2	4,5	1928,8	13,7	-9,9	-2,9	-4,8	-3,1
Slovenia	36,2	2,7	1604,0	12,0	-21,1	-7,4	-13,9	-11,5
10 New MS	673,9	126,4	53331,1	444,5	-19,1	-5,8	-9,3	-6,5
Bulgaria	69,4	7,9	3910,0	21,6	-18,3	-11,1	-13,8	-13,3
Romania	289,2	23,7	13432,2	91,3	-20,3	-12,5	-16,0	-10,4
Bulgaria/Romania	358,7	31,7	17342,2	112,9	-19,9	-12,1	-15,5	-11,0
EU27	8466,8	857,1	443506,9	2984,0	-18,7	-9,5	-13,2	-8,9

In the next Table it can be seen that on the one side, CH_4 emissions from enteric fermentation fall by -20.7%. Mineral fertilizer emissions, on the other side, are not much affected (-2.1%). Here we can already predict the big changes in production patterns due to such a livestock tax. These are presented in the following section.

Table 8.33: Change in emissions per inventory position for the EU according to the livestock emission tax scenario

	Baseline (REF, 2020)				Livestock emission tax (LTAX, 2020)			
	EU15	EU10	BUR	EU27	EU15	EU10	BUR	EU27
	[1000t]	[1000t]	[1000t]	[1000t]	[% to REF]	[% to REF]	[% to REF]	[% to REF]
Methane emissions from enteric fermentation (IPCC)	6002.4	555.7	328.6	6886.6	-20.7	-20.8	-20.5	-20.7
Methane emissions from manure management (IPCC)	1431.8	118.2	30.1	1580.1	-9.6	-11.0	-14.0	-9.8
Methane emissions	7434.2	673.9	358.7	8466.8	-18.6	-19.1	-19.9	-18.7
Direct nitrous oxide emissions stemming from manure managment and application except grazings (IPCC)	173.8	31.4	8.0	213.2	-13.9	-11.7	-15.9	-13.7
Direct nitrous oxide emissions stemming from manure management (only housing and storage) (IPCC)	*103.2*	*20.7*	*5.8*	*129.6*	*-16.5*	*-12.6*	*-16.7*	*-15.9*
Direct nitrous oxide emissions stemming from manure application on soils except grazings (IPCC)	*70.6*	*10.7*	*2.2*	*83.5*	*-10.2*	*-10.1*	*-14.0*	*-10.3*
Direct nitrous oxide emissions from anorganic fertilizer application (IPCC)	183.8	42.5	6.4	232.7	-2.8	0.5	-0.9	-2.1
Direct nitrous oxide emissions from crop residues (IPCC)	73.9	12.2	7.5	93.6	-8.8	-5.2	-10.9	-8.5
Direct nitrous oxide emissions from nitrogen fixing crops (IPCC)	12.2	1.1	0.7	14.0	-12.2	-13.8	-12.7	-12.3
Direct nitrous oxide emissions from atmosferic deposition (IPCC)	15.0	2.9	1.9	19.8	-2.5	-1.0	-3.7	-2.4
Indirect nitrous oxide emissions from ammonia volatilisation (IPCC)	41.9	7.6	2.0	51.5	-10.1	-6.2	-11.9	-9.6
Indirect nitrous oxide emissions from leaching (IPCC via Miterra)	15.1	3.6	0.7	19.4	-32.1	-42.6	-56.3	-35.0
Direct nitrous oxide emissions from cultivation of histosols (IPCC via Miterra)	108.8	20.7	0.2	129.7	-2.7	-0.8	-5.0	-2.4
Nitrous oxide emissions	699.1	126.4	31.7	857.1	-10.0	-5.8	-12.1	-9.5
Carbon dioxide equivalent emissions (global warming potential)	372833.6	53331.1	17342.2	443506.9	-13.6	-9.3	-15.5	-13.2
Ammonia emissions	2426.5	444.5	112.9	2984.0	-9.3	-6.5	-11.0	-8.9

8.4.4.2 Analysis of economic effects

The introduced tax increases the costs per animal activity in the supply model depending on their emission intensities, which leads to a reduction in livestock, with a particular high impact on ruminants. The additional tax costs for cattle and beef production causes a reduction of land use (grassland) by around -4.2% in EU15 and -4.5% in EU10. Arable land did not compensate this reduction, indicating that it was mainly reduced in areas with high grassland share and that land is not anymore used for agricultural production. In addition, the cut of herd sizes and although prices for beef and milk products increased, drastic income losses for farming in EU15 by –15% and in EU10 by -18% are found. Producer prices increase for beef by +20% in EU15 and by +10% in EU10 and prices for dairy products increase by +7% in the EU15 and by +10% in the EU10. This is the outcome from a rather moderate reduction of the demand, on the one hand, and the deep cut of supply for beef, sheep and goat meat on the other hand. Total meat supply is reduced by -5.4% in EU15 and by –4% in EU10, whereas meat supply from ruminants such as beef, sheep and goat meat is even more affected. Beef meat supply declines by -23% in EU15 and -28% in EU10. For sheep and goat meat the reduction range is similar. The supply for dairy products such as butter or fresh

milk products is also reduced, in EU15 less strong (between -1% and -17%) than in EU10 (between -7% and -27%). As consequence of the supply drop and higher prices, imports into EU-27 increased for meat by +49% for dairy products by +7% and at the same time exports decreased in EU-27 by -9% for meat and -8% for dairy products.

Table 8.34: Change in income, area, yield and supply for the EU-27 for activity aggregates according to the livestock emission tax scenario

	Baseline (REF, 2020)				Livestock emission tax (LTAX, 2020)			
	Income	Area	Yield	Supply	Income	Area	Yield	Supply
	[Eur hd or ha]	[1000 ha]	[kg/ha or hd]	[1000 t]	*[% to REF]*	*[% to REF]*	*[% to REF]*	*[% to REF]*
Cereals	550	56737	5750	326227	-4,8%	0,4%	-1,6%	-1,3%
Oilseeds	328	10034	2917	29266	-2,1%	2,0%	-1,0%	1,0%
Other arable crops	864	8185	19874	162678	-4,7%	-0,1%	3,2%	3,1%
Vegetables and Permanent crops	6131	15092	11525	173932	0,0%	-0,1%	0,1%	0,1%
Fodder activities	274	80976	23060	1867313	2,2%	-5,5%	-11,4%	-16,2%
Set aside and fallow land	135	14976			-0,4%	7,1%		
Utilized agricultural area	1287	187450	13656	2559779	-14,0%	-1,6%	-10,4%	-11,8%
All cattle activities	461	84745	93	7907	-70,3%	-24,8%	2,6%	-22,8%
Beef meat activities	152	27015	362	9785	-192,7%	-39,6%	-5,6%	-43,0%
Other animals	110	394741	776	306251	-3,3%	-7,0%	5,6%	-1,8%

While there are no severe changes in dairy cow supply in the EU15 (-4% in herd size and production), reductions in the EU10 are more pronounced (with -13% in herd size and -12% in production), resulting in an overall EU-27 reduction in herd size by -6% and -5% in production. As expected, the tax per animal results in very drastic production costs and income losses for European farmers. As already mentioned, decreases in beef meat activities are very high in almost all MS. EU-27 is projected to face a reduction in beef herd by -40% and -23% in production.

Table 8.35: Beef cattle herds and beef market balances per Member State according to the livestock emission tax scenario

	Reference year (2020)				Livestock emission tax (LTAX, 2020)			
	Beef* herd [1000 hd]	Production [1000 t]	Demand [1000 t]	Net trade [1000 t]	*Beef* herd [% to REF]*	*Production [% to REF]*	*Demand [% to REF]*	Net trade [Δ to REF]
Austria	544	180	126	54	*-42%*	*-26%*	*-8%*	-36
Belgium-Lux.	694	280	190	90	*-37%*	*-21%*	*-8%*	-43
Denmark	341	113	213	-101	*-65%*	*-42%*	*-10%*	-26
Finland	232	77	95	-17	*-45%*	*-28%*	*-7%*	-15
France	6405	1698	1621	77	*-30%*	*-18%*	*-9%*	-158
Germany	1698	955	565	390	*-54%*	*-34%*	*-8%*	-282
Greece	317	46	142	-96	*-36%*	*-5%*	*-19%*	26
Ireland	2599	615	86	529	*-45%*	*-26%*	*-18%*	-142
Italy	2463	935	1279	-345	*-22%*	*-14%*	*-11%*	10
Netherlands	62	334	370	-36	*-24%*	*-17%*	*-11%*	-16
Portugal	642	128	200	-72	*-54%*	*-11%*	*-11%*	9
Spain	4501	725	798	-74	*-48%*	*-24%*	*-19%*	-23
Sweden	352	125	268	-143	*-46%*	*-29%*	*-8%*	-15
United Kingdom	3560	810	1370	-559	*-47%*	*-26%*	*-13%*	-37
EU15	24411	7021	7325	-304	*-40%*	*-23%*	*-11%*	-750
Cyprus	17	5	6	-1	*7%*	*2%*	*-21%*	1
Czech Republic	121	61	24	37	*-69%*	*-38%*	*-46%*	-12
Estonia	25	12	4	8	*-62%*	*-42%*	*-52%*	-3
Hungary	47	32	28	3	*-39%*	*-12%*	*-59%*	13
Latvia	63	20	21	-1	*-25%*	*-19%*	*-27%*	2
Lithuania	57	32	14	18	*-39%*	*-16%*	*-23%*	-2
Malta	4	2	10	-8	*2%*	*-1%*	*-21%*	2
Poland	859	365	216	149	*-40%*	*-33%*	*-27%*	-61
Slovac Republic	35	30	21	10	*-18%*	*-5%*	*-62%*	11
Slovenia	123	51	62	-11	*-44%*	*-13%*	*-31%*	12
10 New MS	1351	609	406	204	*-41%*	*-28%*	*-32%*	-37
Bulgaria	225	58	68	-9	*-18%*	*-13%*	*-32%*	14
Romania	1028	218	215	3	*-25%*	*-21%*	*-13%*	-17
Bulgaria/Romania	1253	276	283	-7	*-24%*	*-19%*	*-18%*	-3
EU27	27015	7907	8014	-107	*-40%*	*-23%*	*-13%*	-790

* 'Beef herd' = suckler cows + adult cattle for fattening in this table.

The regional herd size reduction in percentage compared to the baseline for beef meat activities is presented in Figure 8.7. The reduction is very high in all regions and the distribution depends on the dominating farming system.

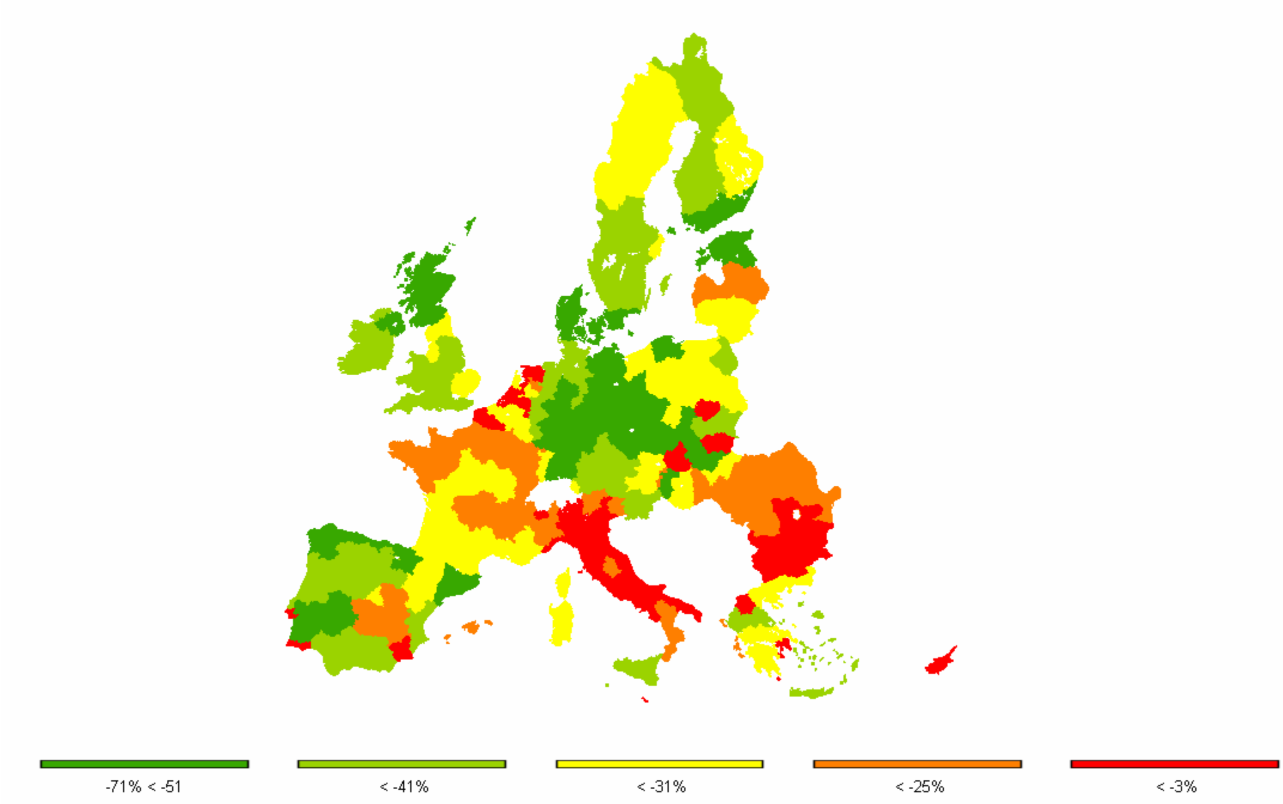

Figure 8.7: Change in herd sizes for beef meat activities according to the livestock tax scenario (in %)

Figure 8.8 presents the percentage changes of income after the livestock tax is introduced. In this scenario exercise it is assumed that no tax money is re-distributed to the farmer and that the tax is part of the variable cost of production. The average income reduction in the EU-27 is -18.3%, as the histogram of Figure 8.8 shows.

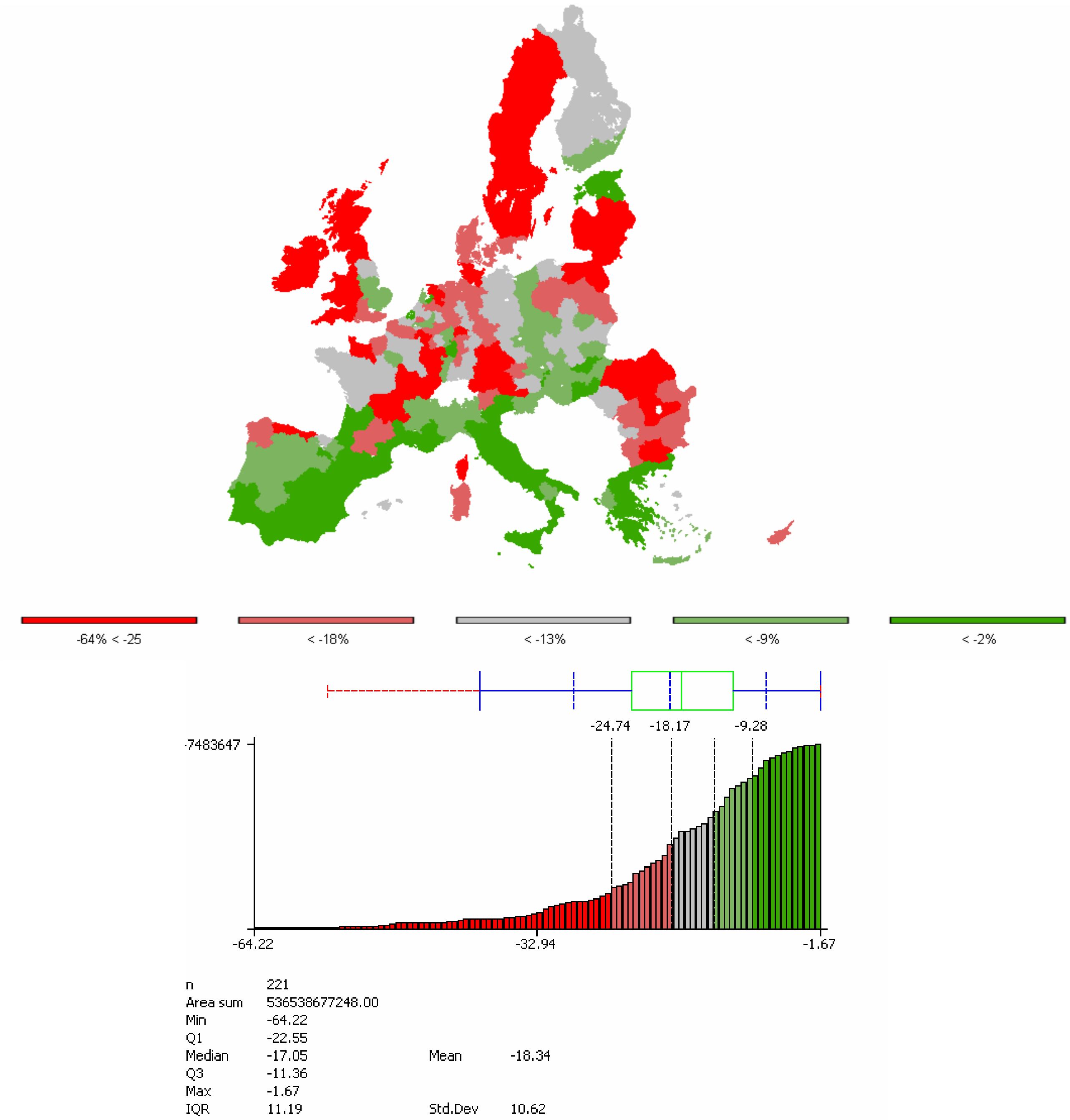

Figure 8.8: Change in agricultural income per utilised agricultural land according to the livestock tax scenario (in %)

8.4.4.3 Analysis of environmental effects

In the livestock emission tax scenario nitrogen surplus is clearly less reduced than in the previous scenarios. This has to do with the fact that arable crops are much less affected, so that N_2O emissions (N-based emissions) are less affected. The adjustment burden is, as mentioned on animals, and therefore mostly on CH_4 emissions. The observed reduction in -11% is mostly due to less nitrogenous emissions from manure management.

Table 8.36: Changes in the nitrogen balance according to the livestock emission tax scenario

		Baseline year (REF, 2020)				Livestock emission tax (LTAX, 2020)			
		EU15 [1000 t N]	EU10 [1000 t N]	BUR [1000 t N]	EU27 [1000 t N]	EU15 *[% to REF]*	EU10 *[% to REF]*	BUR *[% to REF]*	EU27 *[% to REF]*
Import by mineral fertilizer	(+)	10915	8844	2070	11227	*-2%*	*-3%*	*1%*	*-2%*
Import by manure	(+)	8782	7780	1001	9177	*-15%*	*-15%*	*-11%*	*-15%*
Import by crop residues	(+)	5674	4812	862	6204	*-8%*	*-9%*	*-5%*	*-8%*
Biological fixation	(+)	971	894	77	1036	*-11%*	*-11%*	*-14%*	*-11%*
Atmospheric deposition	(+)	1983	1659	324	2174	*-2%*	*-2%*	*-1%*	*-2%*
Nutrient retention by crops	(-)	17467	14760	2707	18755	*-6%*	*-7%*	*-3%*	*-6%*
Surplus total	(=)	10856	9229	1628	11063	*-10%*	*-11%*	*-5%*	*-10%*
Gaseous loss	(-)	3714	3141	573	3868	*-10%*	*-10%*	*-6%*	*-10%*
Run off mineral	(-)	376	261	115	403	*-2%*	*-3%*	*1%*	*-2%*
Run off manure	(-)	413	342	71	449	*-14%*	*-15%*	*-11%*	*-14%*
Surplus at soil level	(=)	6354	5484	869	6344	*-11%*	*-12%*	*-4%*	*-11%*

Yields in fodder activities (mainly fodder maize) decrease by -11%, driven by the reduction in the cattle herd size. Yields in beef meat activities decrease by -6%. There is regional differentiation so "classical cattle production regions" are more affected and face larger reduction in herd sizes, larger reduction in fodder consumption and larger extensification effects.

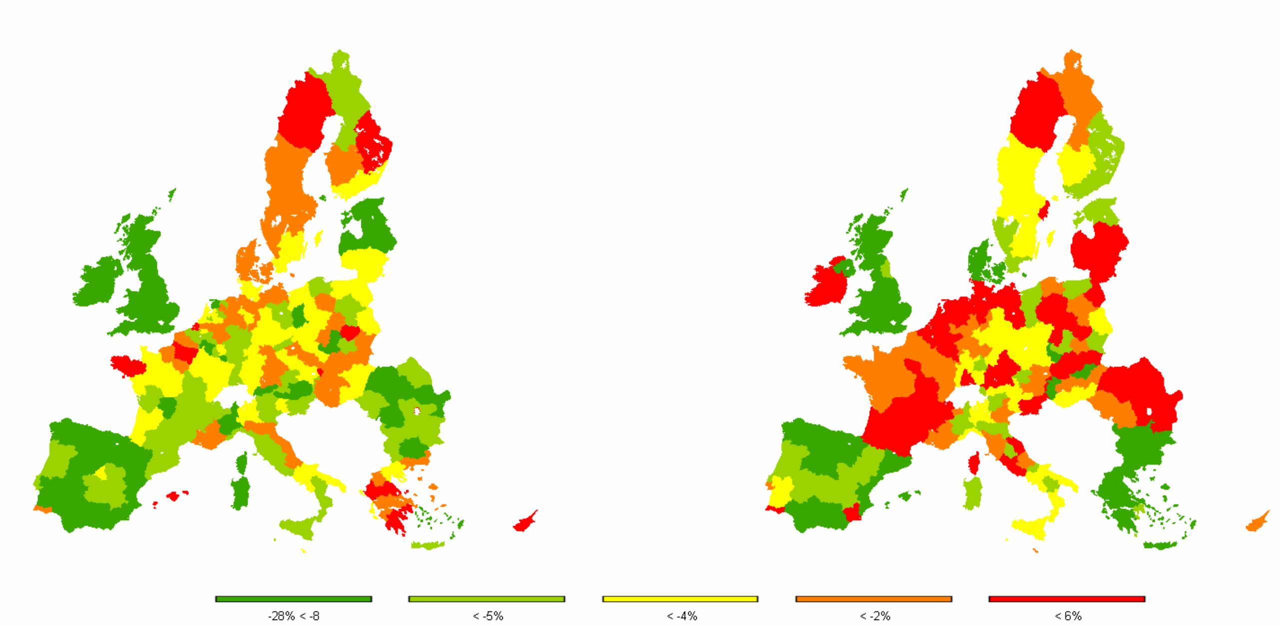

Figure 8.9: Yield changes in fodder (left) and beef activities (right) according to the livestock tax scenario

8.4.5. Results from introducing emission leakage into the scenario analysis

For the interpretation of the overall effects on GHG emissions it would be important to assess and account not only for those emissions resulting from production changes within the EU but also outside the EU. The emission abatement policy scenarios analysed with the current CAPRI version

took only agricultural production activities within the EU into account. Such emission estimates can be used to assess the direct GHG emissions from EU agriculture from the supply side. If the issue of GHG emissions is instead viewed from the demand side, then it is not longer sufficient to assess only the impact of European production. The agricultural markets of the EU are closely linked with other regions around the world via trade flows, and significant shares of consumption, depending upon the product considered, can be imported. Thus, a more comprehensive assessment of GHG emissions should also take into account import substitution.

8.4.5.1 Method used for this exercise

The CAPRI system contains a fairly detailed trade model, where 28 world regions trade bilaterally in around 40 agricultural commodities. If per-commodity emission coefficients were estimated for those commodities, the trade model would be capable of computing indirect effects on global GHG emission of EU policy changes.

In order to estimate such coefficients, three sources of information are combined:

1. GHG inventory estimates for world regions provided by JRC/IES (Joint Research Centre-Institute for Environmental Sustainability). The data set is called the Edgar database[22], and it contains time series of inventories for a large set of countries, similar to the regions used by FAOSTAT.
2. Agricultural production statistics from the FAO, also in time series.
3. Emission factors per commodity for the EU. Those coefficients are used as *priors*[23] in the estimation.

The Edgar inventories are structured in a way similar to the IPCC tier 2, with gross emissions per gas (N_2O, NH_3 and CH_4) and source (enteric fermentation, fertilizer application etc.), occasionally differentiated by production type, where in particular beef and milk production has separate entries. However, the Edgar inventories do not give any information about emissions per product as required in CAPRI.

The production statistics from FAO were aggregated to obtain the product classification used in CAPRI, and the objective of the estimation is to find emission factors per ton of commodity in the FAO dataset such that the Edgar inventories are recovered, or, to find coefficients b such that

$$y_{it} = \Sigma_k(b_{ik}x_{tk}), \qquad (8.1)$$

where y is the Edgar data on inventory position i in year t, and x is the FAOSTAT production data on product k in year t.

Since there is only a limited number of years with data for each region that covers the relevant product in both Edgar and FAO, the problem of inferring product specific coefficients is generally

[22] EDGAR database v4.00, including data of agricultural emissions for 1970-2005 for all available countries split by IPCC categories. Ammonia emissions are not recorded in EDGAR and, therefore, not part of the emission leakage module.

[23] In Bayesian statistical inference, a prior probability distribution (called simply the prior) of an uncertain quantity p is the probability distribution that would express one's uncertainty about p before the "data" are taken into account. A prior is often the purely subjective assessment of an experienced expert, in our case "average EU emission factors per agricultural commodity".

ill-posed (underdetermined). This means that there can be many different sets of emission factors that all equally well reproduce the Edgar data.

If a country produces few commodities and there are many years of data, there may be no coefficients at all that exactly satisfies the Edgar data for all years, in particular as we require the coefficients to be constant over time. Therefore, equation (8.1) needs to have error terms. It seems reasonable to assume that the error in the inventory y is much larger than that of x, because x is physically measurable whereas y depends on computations, which in turn depend on some output measurement. Therefore, we assume that our data on inventories in the Edgar database (Y) relate to the true emissions (y) with a multiplicative error (e), i.e. $Y_{it} = y_{it}e_{it}$, where $e_{it} \sim N(1,\sigma_t^2)$ for all i.

In order to resolve the (indeterminacy) some method is needed to distinguish between any two alternative sets of coefficients that equally well satisfy equation (3.1). We achieve this by introducing the assumption that *a-priori* (i.e. before seeing the data), the emission factors are the same as in the EU, and then letting the estimates deviate from the priors insofar this is needed in order to satisfy equation (3.1). As prior distribution of emission factors we choose the density b_{ik} $\sim \underline{b}_{ik}N(1.1/(r_{ik}s_{ik}))$, where the prior emission factor is $\underline{b}$ and rs is the so-called precision. The greater the precision, the less are the estimates b allowed to deviate from the prior. This particular functional form for the prior density function was chosen because, if the factor s of the precision is appropriately set and the sample small, then any deviations from the priors that is necessary in order to meet the data constraints is inversely proportional to r, which we call the "reliability factor". For example, if r_{ik} is for some inventory positions i the same for all products k (e.g. $r_{ik} = 1 \; \forall \; k$), then a deviation is uniformly distributed across all commodities, and if for some commodity r would be twice as high as for the other commodities (coefficient *a-priori* twice as reliable) then the associated coefficient is adjusted only half as much for that commodity as other commodities. The derivation of the factor s to obtain those properties mentioned above is considered too technical to fit in this report (see Jansson et al. 2010).

The prior expectation $\underline{b}$ was set to equal the average (across regions) of all EU emission factors, and the reliability factor r was set to the inverse of the variance of $\underline{b}$. The latter implies that if factors are generally similar in all EU regions, the factor is considered "reliable", but if it is generally different across EU regions, then it is also a less reliable prior for a region outside of the EU.

The more observations that are available (years of data), the less important will be the prior. When only a few years of observations are available, the relative importance of the data versus the prior is influenced by the ratio of σ_t^2 / (1/rs). Obtaining an estimate of σ is not trivial. We opted for the naïve but transparent approach of introducing a prior distribution of σ_t^2 too, stating that $\sigma_t = 0.1(T - t + 1)$, where T is the total number of years, for all commodities and regions. This means that, based on the "three-sigma-rule" and based on the fact that $1/\sigma^2$ is the weight of an observation in the estimation, essentially all outcomes are within ± 30% of the mean in the latest year, but that greater deviations are considered more likely in older years.

As summary information, the presented exercise makes use of 46892 observations (information from EDGAR over countries, emission sources and years) and returns 18456 emission coefficients.

In the table below we present a selection of results for 4 commodities, 4 countries and 2 emission sources[24].

Table 8.37: Emission coefficients for selected countries, products and gas sources (in kg of methane or nitrous oxide per ton of product)

		Potatoes			Wheat			Beef			Cow milk		
		pmod	amod	nobs	pmod	amod	nobs	pmod	amod	nobs	pmod	amod	nobs
USA	N2OSYN	0.06	0.06	14.00	0.29	0.30	14	2.08	2.36	14	0.06	0.28	18
	CH4ENT	-	-	-	-	-	-	680.10	415.79	14	21.11	21.88	18
Canada	N2OSYN	0.06	0.06	14.00	0.29	0.29	14	2.08	2.22	14	0.06	0.31	18
	CH4ENT	-	-	-	-	-	-	680.10	570.59	14	21.11	21.63	18
Argentina	N2OSYN	0.06	0.06	14.00	0.29	0.27	14	2.08	1.80	14	0.06	0.10	18
	CH4ENT	-	-	-	-	-	-	680.10	923.15	14	21.11	35.93	18
China	N2OSYN	0.06	0.06	14.00	0.29	0.31	14	2.08	2.61	14	0.06	1.82	18
	CH4ENT	-	-	-	-	-	-	680.10	1,047.21	14	21.11	45.40	18

* N2OSYN: direct nitrous oxide emissions from anorganic fertilizer application; CH4ENT: methane emissions from enteric fermentation

Note: pmod: prior mode for the emission coefficient (calculated for the EU-27), amod: average estimated emission coefficient (over years), nobs: number of observations (years of EDGAR data for the estimated emission source).

The presented results show that a ton of beef produced in United States implies 415 kg of enteric fermentation CH_4 emissions (whereas the prior information from the EU-27 is 680 kg of CH_4). By doing a back of the envelope calculation, we can see that an average 'beef producing activity'[25] in the EU-27 is producing 0.25 tons of beef and emits around 104 kg of CH_4. Out of the estimation we can deduct that, based on the existing information on emission inventories (EDGAR) and production figures (FAOSTAT), enteric fermentation emissions per beef producing activity in the US are higher than in the EU and/or beef yields are lower in the US with respect to the EU. We also observe a higher allocation of enteric fermentation emissions to milk production in the US than in the EU (21.88 and 21.11 kg of CH_4 respectively). Implausible results can be observed for Argentina and China (923/1047 kg of CH_4 per ton of beef and 36/45 kg of CH_4 per ton of milk), what can be provoked by inconsistencies between emission inventories and production statistics.

In the case of N_2O emitted through the synthetic fertilizer application, emission coefficients for crop products range between 0.06 for potatoes and 0.29 for wheat. Beef and milk production has also been allocated emissions from synthetic fertilizer application indirectly through feeding.

8.4.5.2 Estimation of Emission leakage in the EU

Emission leakage can here be understood as the indirect effect on emissions in non-EU countries induced by the implementation of an EU policy. As shown in the previous sections on the emission abatement policy scenarios, all the policies analysed show an impact on agricultural production in

[24] This is only an example, the full set of results is available from the authors upon request.
[25] Here we include the whole cattle chain, including beef production from bulls (low and high weight), suckler cows, fattening calves, fattening heifers and dairy cows.

the EU. The changed production in the EU influences prices, production and trade also in other regions of the world, thereby indirectly affecting the global emissions. Using the commodity-specific emission factors, the change in production in the rest of the world can be translated into a change in emissions outside of the EU. The results of such a computation are shown in the Table below.

Table 8.38: Change in emissions outside of the European Union induced by the policies in the European Union, relative to reference scenario (1000 t per year)

	ESAA [1000t]	ETSA [1000t]	LTAX [1000t]	STD [1000t]
Methane emissions from enteric fermentation (IPCC)	281	191	789	301
Methane emissions from manure management (IPCC)	43	31	25	44
Methane emissions	324	222	814	346
Indirect nitrous oxide emissions from ammonia volatilisation (IPCC)	0.73	0.49	1.34	0.78
Direct nitrous oxide emissions stemming from manure application on soils except grazings (IPCC)	1.68	1.10	2.47	1.73
Direct nitrous oxide emissions from crop residues (IPCC)	0.42	0.48	-1.07	0.47
Direct nitrous oxide emissions stemming from manure managment on grazings (IPCC)	3.21	2.17	8.83	3.42
Direct nitrous oxide emissions from cultivation of histosols (IPCC via Miterra)	-0.13	-0.10	-0.26	-0.09
Indirect nitrous oxide emissions from leaching (IPCC via Miterra)	0.12	0.12	0.15	0.16
Direct nitrous oxide emissions stemming from manure management (only housing and storage) (IPCC)	0.63	0.37	1.18	0.62
Direct nitrous oxide emissions from anorganic fertilizer application (IPCC)	0.92	1.19	-0.03	1.40
Nitrous oxide emissions	5.30	4.35	8.97	6.15
Carbon dioxide equivalent emissions (global warming potential)	8,447	6,014	19,866	9,163

The computations indicate that the GHG emission abatement policies in the EU induce increased emissions elsewhere, as could be expected, but that the effect on emissions outside of the EU is different depending on the way in which the emission abatement in the EU is achieved. The last row of Table 8.38 shows the change in total GHG fluxes in $CO_{2\text{-eq}}$. The livestock tax scenario induces an increase in about 20 million tons of GWP, which is more than three times as much as the 6 million tons of GHG fluxes of the scenario with tradable permits. The two scenarios with emission standards also result in lower increases in global emissions than the livestock tax scenario, with about 8.5 million tons of extra GHG fluxes with effort sharing agreement and 9 million tons extra without the effort sharing.

A look into the detailed rows of Table 8.38 reveals that the main explanation for the differences between the scenarios is to be sought in the ruminating livestock sector, since the difference between the scenarios is most strongly influenced by the difference in the first line of the table,

"CH_4 emissions from enteric fermentation". In the livestock tax scenario, some of the reduction in EU beef meat production is replaced by imports from primarily Mercosur countries such as Brazil and Argentina, where the estimated emission factors per ton of beef are higher than those of the EU (0.92 kg CH_4 from enteric fermentation per kilo beef produced in Argentina as opposed to 0.68 in the EU (estimation results not shown in the table). In the other scenarios, the abatement is spread across more agricultural sectors, where imported substitutes have emission factors that are smaller than or more similar to the EU emission factors.

The results indicate that from a global emission abatement point of view, the tradable emission permit policy is most efficient for reducing global emissions (this is because it allocates the emission cut within the EU-27 according to where it costs least to achieve), whereas the livestock tax policy is the least efficient (because it does not discriminate according to the potential for cutting emissions and loads the adjustment cost onto just one production factor).

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 examplarily for two aspects that have not been covered in the main part of the study: (i) environmental impacts other that 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 thus not directly comparable with the results obtained for European livestock production obtained with the CAPRI model.

9.1. Overview of the impact of the livestock sector on EU biodiversity

Author: Katarzyna Biala

9.1.1. Introduction

This chapter provides an overview of the effect of the livestock sector in Europe on the conservation and loss of biodiversity, Even though the main focus of the project is on GHG and NH_3 fluxes, a better understanding on the impact on biodiversity if important so that potential synergies and trade-offs between different policy objectives, such as climate and biodiversity protection, can be considered.

Europe has a great variety of landscapes resulting from the interaction of human activities with different biophysical conditions. Along centuries, agriculture has played an important role in shaping and managing these landscapes (Baldock and al., 1995; Vos & Meekes, 1999). Traditional land use systems, including livestock production and mixed farming systems, have contributed positively to the preservation of biodiversity, providing suitable conditions to host a wide spectrum of flora and fauna species (Bignal and McCracken, 1996). Plieninger et al. (2006) point out that traditional land use in Europe has fostered habitat and species richness and created rural landscapes with a high nature conservation value. Semi-natural habitats in farmland are European biodiversity hotspots. For example, at European scale, agricultural habitats have the highest overall bird species richness among all other habitats (Tucker, 1997) and more than half of European butterfly species live in traditionally managed grassland habitats (Ouin and Burel, 2002; van Swaay and Warren, 2003). Links with livestock raising and, in particular, grazing or mowing, is crucial for the overwhelming majority of those areas (Baldock et al., 1995) and for the conservation of High Nature Value farmland.

Concerns over negative impacts of farming on biodiversity are a result of unprecedented rapid agricultural intensification in the second half of the 20th century (Benton et al., 2003), which has caused widespread farmland biodiversity decline and affected other plant and animal communities. Intensification and specialisation also bring about landscape changes, resulting in its

homogenisation and destruction of traditional landscape elements and, consequently, loss of habitats. Marginal areas, on the other hand, are threatened with cessation of agricultural practices and land abandonment. In the last decade, however, biodiversity loss has been given increased attention and has been awarded a higher political profile, in particular as a result of adopting at the pan-European level in 2003 the target of halting biodiversity loss by 2010 (EEA, 2010). Consequently, various efforts have been made to further merge biodiversity conservation into agricultural policy.

Impacts of agricultural intensification occur predominantly via (direct and indirect) effects on land use (changes) and nutrient element cycling (Oenema et al. 2007). The biophysical processes behind these effects are numerous and interacting that it is difficult to ascribe a particular biodiversity response to an individual agricultural cause (Firbank et al., 2008). Rather, most biodiversity changes are responses to a suite of agricultural changes that can be regarded together as agricultural intensification on the one hand, or habitat restoration or abandonment on the other.

Therefore, to date, no comprehensive assessment of the impact of livestock production systems in Europe on biodiversity has been performed. The challenge for such an assessment is linked to the complexity of the interrelationships between biodiversity, environment and agriculture, as explained by Firbank et al. (2008). This chapter aims at providing such a comprehensive analysis of the livestock impacts on biodiversity, taking as a point of departure the intensity levels of European agriculture and then identifying evidence of causal links with animal production based on extensive research of the currently available source materials. We base our analysis on results from extensive research carried out in the frame of European or national research projects and published in the peer-reviewed literature. These projects were evaluating aspects of pressures as well as benefits for biodiversity originating from livestock production systems on the basis of models, field studies and literature data. Overview of livestock impacts on 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. The chapter does not address livestock impacts on marine biodiversity.

Most of research was focusing on negative effects of livestock production systems on biodiversity, as presented in Section 9.1.3. The two main areas of research are impacts of emissions of reactive nitrogen and habitat loss and fragmentation and they are the main sources of information for the current review. The reason is the predominance of intensive production systems in Europe with respect to extensive production systems, but also because most studies were concerned with assessing/reducing the negative effects.

Furthermore, it is important to stress that many of the effects described below have been attributed to agriculture in general or to pressure on available land and not to livestock production in particular. In case such a relationship is evident it will be clearly identified.

On the other hand, there is a substantial body of scientific evidence of benefits of livestock production systems, in particular grazing for maintaining biodiversity-rich habitats and traditional landscapes in Europe, which is presented in Section 9.1.4.

9.1.2. Major livestock categories and intensity of production systems

Chapter 2 shows that livestock in EU-27 is dominated by cattle (both dairy and beef), pigs and poultry. Small ruminants – sheep and goats are particularly important in the Mediterranean Member States (incl. Portugal), as well as in Bulgaria, Romania, Hungary, Czech Republic and the UK (sheep). Pigs and poultry are generally associated with intensive, indoor methods of production; outdoor, free-range husbandry of pigs and poultry is marginal, although the latter has been on the increase recently and therefore cannot be considered in this review.

Dairy farming systems show high diversity throughout Europe. However, most of the dairy production is in high input/output systems (83% of total EU dairy cow numbers and 85% of total EU milk production) whereas low input/output systems account for 6-8% of total EU dairy cow numbers and 4-5% of total EU milk production. Modern dairy systems are largely dependent upon intensively managed grassland where the structure and composition of the sward is very limited (Adas, 2007). Dairy units are typically fed silage rather than hay. Grassland grown for silage is typically highly fertilised and reseeded low in biodiversity. Cutting for silage – earlier and more frequent than for hay – is a restrictive factor for plants to flower and set seed (Noesberger et al., 1998; Adas, 2007) and those grasslands often do not provide adequate source of food and shelter for beneficial arthropods and vertebrate fauna.

Beef production systems are equally varied in Europe. However, as beef cattle can utilise unimproved pasture, coarse vegetation or wet grassland they may be an important tool in managing such areas (Adas, 2007).

Sheep and goat production vary in intensity between the Mediterranean zone (more intensive) and other areas in Europe. Sheep grazing is considered vital for maintaining many biodiversity-rich habitats.

9.1.3. Adverse effects of livestock production systems on biodiversity

The present chapter discusses potential adverse effect of livestock production systems on biodiversity: impacts from losses of reactive nitrogen to the environments, both as atmospheric pollutants and pollutants to the hydrosphere (section 9.1.3.1) and effects caused by habitat loss and fragmentation (section 9.1.3.2). An identification of areas under risk to biodiversity from livestock sector in Europe has been performed in the EnRisk project (Delbaere & Nieto Serradilla, 2004). In EnRisk, the risks from agriculture to biodiversity and landscapes were quantified and risk indicators developed. In the annex to this chapter we show the results for areas in Europe which are likely to loose breeding bird species that are associated to selected agro-ecosystems due to pressure from high livestock density.

9.1.3.1 Emissions of reactive nitrogen

Major impacts from animal production systems are linked to excess of reactive nitrogen (Milne 2005) that may accumulate in soils, or be lost to air, groundwater or surface water (Eickhout et al, 2006). Nitrogen deposition, especially ammonia (NH_3), contributing to acidification and eutrofication of soils and water has been identified as one of key driving forces of biodiversity loss (Eppink et al., 2008; Fraser & Stevens, 2008, Wammelink et al.,). Eutrofication results in

depauperation of plant assemblages thorough the increase of a small number of species which become dominant in conditions of increased nutrient availability (Firbank et al. 2008). According to the analysis carried out by the European Environment Agency, in Europe 44% of substances causing eutrophication come from agriculture 22% from road transport; 45% of acidifying substances derive from industry and 27% from agriculture (EEA, 2009).

Several literature sources provide estimations of livestock production emissions. Webb et al. (2005) state that around 75% of European NH_3 emissions come from livestock production. Other estimates attribute up to 95% of NH_3 emissions to agriculture (Leip et al., 2011). There are also some data available at country level, broken down into livestock categories. For instance, in 2000 44% of all UK ammonia emissions came from cattle, including both dairy and beef. Grazing sheep were responsible for ca. 5% of the total UK emissions, pigs 9% and poultry 14% (Adas, 2007). With regard to aquatic ecosystems, Lord et al. (2002) identified livestock as a dominant factor determining the national N surplus, 85% of which was within the grassland sector (fertilizer to grass and livestock feed) and the rest was from pig and poultry sectors – approximately 6% and 9%, respectively.

Reviews by Bobbink et al. (1998) and Krupa (2003) provide a comprehensive analysis of the N pollution (Krupa concentrating on ammonia) on terrestrial and freshwater vegetation in Europe. Those two reviews are the main source of the information below, extended by other relevant case studies. It has to be pointed out, however, that not all of those impacts may be attributed solely to livestock production. In case such a relationship is evident it will be clearly identified.

Increased atmospheric nitrogen inputs affect diversity in many semi-natural and natural ecosystems. Its severity depends on the amount and the duration of inputs as well as on bio-physical conditions in a particular ecosystem, such as buffering capacity, soil nutrient status and soil factors influencing the nitrification potential and nitrogen immobilization rate. Therefore, the sensitivity to air-borne nitrogen of plant communities varies significantly. Ammonia (NH_3) is considered to be the foremost factor of vegetation changes. Most to least sensitive plant species to NH_3 are native vegetation > forests > agricultural crops. In Europe many of the threatened species and biodiversity-rich semi-natural habitats (i.a. grassland and heathlands) depend on the management which mainly consists in removal of nutrients. Ecological modification and successional change by means of N deposition is particularly evident oligotrophic plant communities (= poor in nutrients, including N) as species adapted to N deficiency will be outcompeted by nitrophilous species with higher N demand. This again highlights the importance of maintaining grazing or mowing management for those communities in order to remove excess nutrients.

Direct toxicity of NH_3 was observed on forest vegetation. In the former GDR (East Germany) in the vicinity of huge pig farms with up to 20 000 pigs, forest decline (foliar injury) attributable to NH_3 was observed over areas of 2000 ha. At distances less than approximately 1 km from the source, the forests were completely destroyed.

Apart from direct foliar injury negative effects of N on higher plants include alterations in: growth and productivity, tissue content of nutrients and toxic elements, lowered drought and frost tolerance, weakened response to insect pests and pathogenic microorganisms, inhibition of development of beneficial root symbiotic or mycorrhizal associations or inter-species competition and species loss.

There are a number of valuable European habitats which have been shown to be seriously threatened by N deposition.

Fresh waters

Fresh waters are among the most sensitive ecosystems with respect to atmospheric acidification. Soft-water lakes (with *Littorelletea uniflorae* plant communities) are characterized by the *presence of rare and endangered plants* (e.g. *Littorella uniflora, Lobelia dortmanna, Isoetes lacustris*) which disappear due to dense plankton blooms or are replaced by common ubiquitous species.

Ombrothrophic (= raised) bogs and wetlands – fens and marshes

Ombrothrophic bogs, which receive all their nutrients from the atmosphere, are particularly sensitive to airborne N loads. Characteristic species include Sphagnum ssp. (bog mosses), sedges and heathers (*Andromeda, Calluna, Erica*) and insectivorous species (e.g. *Drosera*). Absence of those species has been reported from the Netherlands, Denmark and the UK, Germany and Sweden.

Fens are alkaline or slightly alkaline wetlands. Although they have an intermediate sensitivity to N enrichment, their most valuable rare species, orchids, are in decrease. For marshes, on the other hand, N deposition is only a minor threat.

Species-rich grassland

Calcareous grassland (Festuco-Brometea)

Petit & Elbersen (2006) using the MIRABEL assessment framework (Petit et al., 2001) showed that the number of calcareous grasslands potentially at risk of eutrophication and grazing is rapidly increasing in Europe.

Acid and neutral-acidic grasslands

The species of acidic grassland are especially sensitive to N deposition. Research on 68 acid grasslands across Great Britain indicated that long-term, chronic N deposition has significantly reduced plant species richness (Stevens et al., 2004). Species richness declines as a linear function of the rate of the rate of inorganic N deposition, with a reduction of one species per 4-m^{-2} for every 2.5 kg N ha^{-1} year of chronic N deposition.

Montane-subalpine grasslands

They may be sensitive both to eutrophication and acidification.

Heathlands

The negative impacts have been shown for a wide range of European heathlands, including: dry lowland heathlands, inland wet heathlands, upland Calluna vulgaris moorlands and arctic and alpine (grass) heaths.

Forest ground vegetation

Beside the leaf injury of trees N deposition is a significant threat to the ground vegetation and causes the loss of rare species.

9.1.3.2 Habitat loss and fragmentation

Agricultural activities resulting in habitat loss and fragmentation are widely recognized as one of the major causes of biodiversity loss. It has to be remembered, however, that in Europe habitat loss, fragmentation and degradation are also affected by anthropogenic pressures other than agriculture, mainly urban sprawl and soil sealing.

The following effects of habitat fragmentation and loss on plant and animal populations are known (source: Opdam & Wascher, 2004):

- Population decline and extinction,
- Loss of genetic diversity;
- As little as 50% of patches in a sustainable habitat network may yearly be occupied;
- Lower densities due to less effective distribution on individuals over habitat network;
- Effects of large-scale disturbances stronger in more fragmented habitat, causing temporary extinction at the regional level,
- Reduced growth rate causing recovery time from large-scale disturbances to be extended,
- Disruption of biotic interactions, reducing seed setting and rates of parasitism.

Benton et al. (2003) reviewed extensively the empirical literature and showed that habitat heterogeneity is a key to restoring and sustaining biodiversity in temperate agricultural systems. Agricultural intensification resulted in homogenisation of large areas of European rural landscapes. Main mechanisms of this process with special importance for livestock systems included:

- Farmland unit specialization (livestock versus arable) with the loss of mixed farming systems, incompatible with the mainstream intensive practices;
- Consolidation of farm units – larger contiguous areas under common management system;
- Removal of non-cropped areas – loss of semi-natural habitat features, such as ponds, uncropped field margins and scrub;
- Removal of field boundaries – larger fields and hence larger contiguous areas under identical management, as a consequence of maximizing efficiency of agricultural operations where hedgerows and other field boundary structures no longer serve stock-proofing functions.

- Increased duration and intensity of grazing on improved fields – reduced vegetation height and structural heterogeneity.

There are numerous studies which demonstrate that heterogeneity (which also allows for greater habitat connectivity) is associated with diversity for various groups of fauna: birds (Hinsley & Bellamy, 2000, Herzog et al., 2005), butterflies (Collinge et al., 2003) and invertebrates (Duelli et al., 1999).

The benefits of non-cropped habitats and field margins for both flora and fauna are evidenced by Marshall & Moonen (2002). They are crucial for maintaining both stocks and flows of biodiversity.

9.1.4. Livestock grazing and benefits for biodiversity

Grazing animals cause major alterations to botanical composition and vegetation structure (Hester et al. 2005). Grazing herbivores interact dynamically with the vegetation; the structure and quality of vegetation affect the diet of grazing animals and, in turn, the components of grazing (defoliation, excretal return and treading) impact on the species composition and structure of the vegetation (Marriott & Carrère, 1998). Livestock grazing modifies habitats and consequently populations of invertebrates and other organisms at higher trophic levels. Herbivores are thus key drivers of ecosystem function and nutrient dynamics (Duncan 2005). Changes in grazing intensity and the species mix of grazing livestock can therefore exert important influences on biodiversity. There are important differences between domestic grazing species on the grazed plant communities and they may be related to differences in dental and digestive anatomy, but also, and it seems more significantly, to differences in body size (Rook et al. 2004).

Many European grasslands are productive but species-poor as a result of intensification of agriculture. In the recent decades, there was, however, a noticeable phenomenon of de-intensification of those grasslands. It was a result of either the implementation of agri-environmental schemes or the abandonment due to low profitability of animal production based on them. Grazing is suggested as optimum management of de-intensified grassland to enhance biodiversity (Isselstein et al., 2005; Pöyry et al., 2005; Luoto et al., 2003). Extensive grazing was reported to positively influence sward species composition and structure which, in turn, provided favourable conditions for colonizing fauna.

In the Mediterranean region of Europe grazing is essential for the prevention of shrub encroachment (Zaravali et al., 2007). Such a management may include high stocking rates, mixed flocks of sheep and goats, periodic burning and fuelwood collection (Papanastasis & Chouvardas, 2005). If it is altered or becomes less intensive than natural succession leads to the invasion by woody plants.

Grazing is also critical for maintaining many of Europe's cultural landscapes and sustaining rural communities. Over the centuries, pastoralism and transhumance (seasonal movement of livestock between grazing areas) created a wide variety of specific cultural landscapes. The largest remaining extensive pastoral systems on permanent wood pastures in Europe are *dehesa* in Spain and *montado* in Portugal (Finck et al, 2002). Grazing and transhumance are of particular importance for the preservation of open landscapes in the European mountains. Even though transhumance is in

decline in some European mountain regions, in central and southern Europe, however, many viable systems still remain (Steinfeld et al, 2010).

9.1.4.1 Grazing and High Nature Value farmland conservation

Many habitats important for biodiversity conservation are inherently linked to livestock farming. Natural and semi-natural grasslands are biodiversity hotspots in Europe. They are a core component of NATURA 2000 Special Areas of Conservation (SAC) designated by Member States under the Habitats Directive (Council Directive 92/43/EEC) and considered as being of European importance for their biodiversity value. However, not only natural and semi-natural grasslands but, indeed, the majority of habitats forming NATURA 2000 network, depend to various extent on management practices related to livestock production – grazing or cutting regime or mixed. They can be as diverse as e.g heaths, sclerophyllous grazed forests (dehesa) or freshwater habitats such as turloughs and their biodiversity value may be threatened by the cessation of appropriate management practices.

Semi-natural vegetation (e.g heaths, dehesa and species rich grasslands) is a key component of High Nature Value (HNV) farmland in Europe. Originally, the term HNV was introduced by Baldock et al. (1993, 1995) in their studies of the general characteristics of agricultural low-input systems in terms of management practices.

The analysis presented here is based on a conceptual definition for HNV farmland as proposed by Andersen et al. (2003) "*those areas in Europe where agriculture is a major (usually the dominant) land use and where agriculture supports or is associated with either a high species and habitat diversity or the presence of species of European conservation concern or both*". Three types of HNV farmland are defined:

<u>Type 1</u> - Farmland with a high proportion of semi-natural vegetation.

<u>Type 2</u> - Farmland with a mosaic of low intensity agriculture and natural and structural elements, such as field margins, hedgerows, stone walls, patches of woodland or scrub, small rivers etc.

<u>Type 3</u> - Farmland supporting rare species or a high proportion of European or World populations.

Areas of the first type are generally very species-rich, by definition require extensive agriculture for their maintenance and have a well-recognised conservation value. The second type is defined because small-scale variation of land use and vegetation and low agricultural inputs are generally associated with relatively high species richness. The farmed habitats within this type may not necessarily qualify as semi-natural, but the management should be sufficiently extensive to allow for floristic variation. The third type is defined because locally more intensive farming systems may also support high concentrations of species of conservation concern. The three types are not mutually exclusive. Semi-natural grasslands as a rule support many rare species and would thus also qualify as type 3. To a lesser extent the same is true for the mosaics of type 2. In addition, the farmed habitats in type 2 may be partially semi-natural and thus qualify as type 1. Common to all types should be a high contribution to biodiversity conservation at the European level (Paracchini et al., 2008).

HNV farmland is independent of policy designations such as NATURA 2000 (but may overleap with these areas) (Keenleyside & Baldock 2007). The European Environement Agency (EEA) in a preliminary estimate established that around 15 – 25% of the European countryside is HNV farmland (EEA 2004). Afterwards, the methodology for the HNV farmland identification has been developed and refined jointly by EEA and the JRC (see Paracchini et al., 2008, for the recent updates). Figure 9.1 presents the likelihood of HNV farmland presence at EU level.

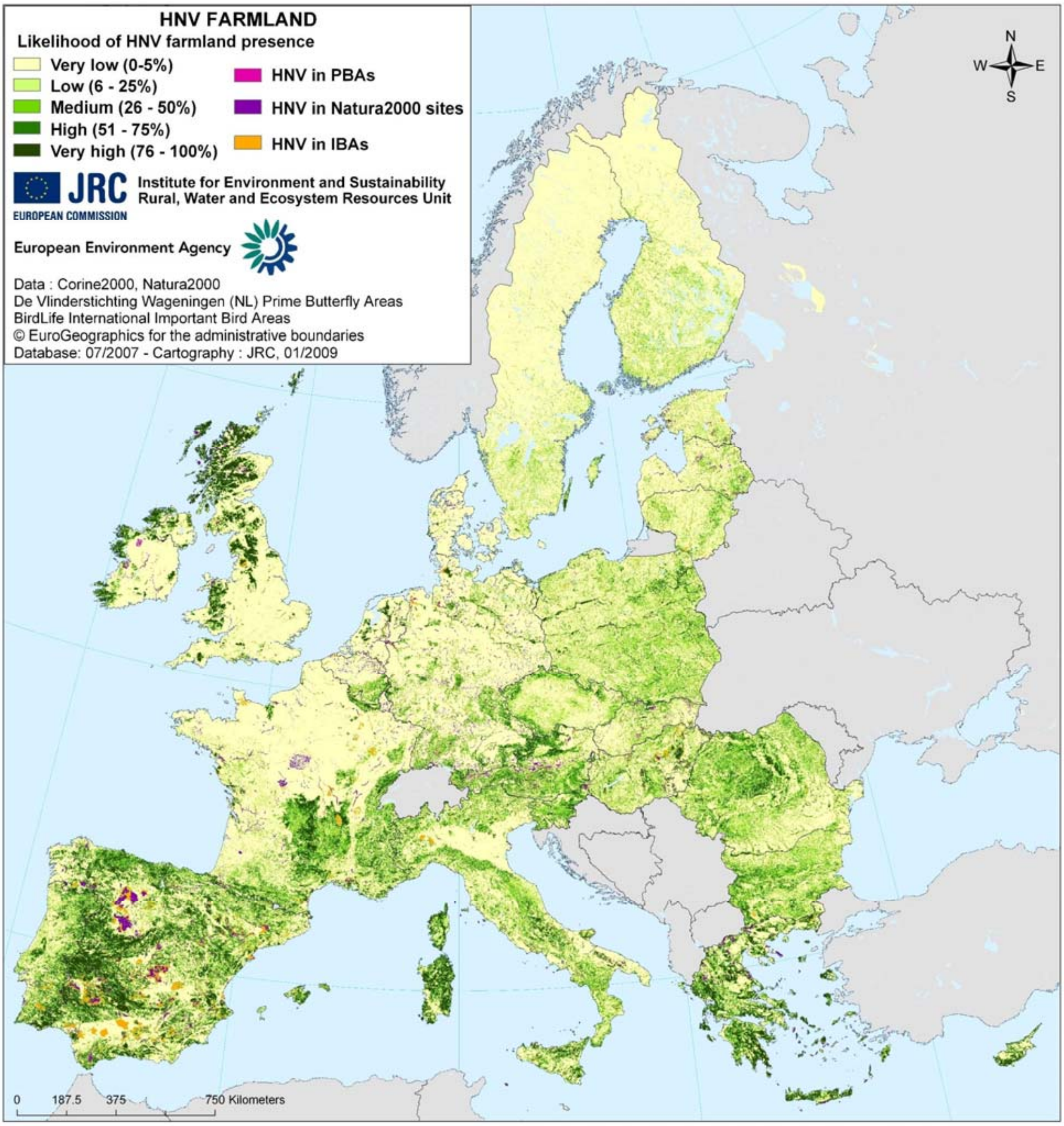

Figure 9.1: Likelihood of HNV farmland presence at EU level (Source: Paracchini et al., 2008)

Utilization through grazing and mowing is essential for the conservation of the majority of HNV farmland habitats. Ostermann (1998) analysed the list of habitats in the Habitat Directive and

estimated that this list contains 65 pasture types that are under threat from intensification of grazing and 26 that are under threat from abandonment.

During the process of methodology development for HNV farmland identification a new list of habitats from Annex 1 of the Habitats Directive that depend on, or are associated with, extensive agricultural practices has been proposed. This list built on a review by the EEA Topic Centre for Nature Protection and Biodiversity and revised a previous proposal by Ostermann, 1998. Following the country consultation period the list of proposed habitats was reviewed again on the basis of country feedback, EEA internal discussions and some expert advice. Detailed information is available in Paracchini et al., 2008.

9.1.5. Conclusions

Interrelationships between livestock and biodiversity are highly complex.

Historically, livestock production in Europe was a decisive factor for the creation and maintenance of traditional landscapes with species-rich, heterogeneous habitats.

In the last decades, though, intensification of agriculture resulted in significant biodiversity loss. There is a wide body of scientific evidence which leaves no doubt that intensive livestock production negatively affects biodiversity not only in farmland but also in other terrestrial and aquatic ecosystems. This is mainly a result of environmental pollution, predominantly through emissions of reactive nitrogen as well as habitat fragmentation and loss.

Quantifying those impacts separately for the livestock sector is very difficult or impossible, due to enormous variety of biodiversity components and the complexity of ecological relationships between them as well as gaps of knowledge of cause-effect links between farming practices and biodiversity.

On the other hand, it is equally evident that grazing is also critical for mainting many of Europe's cultural landscapes such as *dehesa* or *montado* or open landscapes in mountainous areas. Extensive, low-input livestock systems are crucial for maintaining High Nature Value farmland in Europe with its biodiversity-rich semi-natural habitats. EU nature protection instruments, in particular Natura 2000, cover the biodiversity hotspots, leaving aside, however, more common but still valuable parts of HNVfarmland in many areas.

9.2. Estimation of emissions of imported animal products

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9.2.1. Main imports and sources of emissions

The most important imported animal products, in terms of quantity, were identified based on Eurostat statistics on EU animal product imports as presented in Table 9.1.

Table 9.1: Main animal product imports to EU by product and partner in order of importance (Eurostat, 2007).

No	Product	Partner	Amount (ktons)
1	0210 Meat and edible meat offal, in brine, dried or smoked; edible flours and meals of meat or meat offal	BRA	214
2	**0204 Meat of sheep or goats, fresh, chilled or frozen**	**NZE**	**192**
3	**0201+0202 Meat of bovine animals, fresh, chilled, frozen**	**BRA**	**180**
4	**0207 Meat and edible offal, of the poultry (Gallus domesticus, ducks, geese, turkeys and guinea fowls), fresh, chilled or frozen**	**BRA**	**170**
5	160232 Other prepared or preserved meat, meat offal or blood other than sausages and similar products, of fowls of species Gallus domesticus	BRA	150
6	160232 Other prepared or preserved meat, meat offal or blood other than sausages and similar products, of fowls of species Gallus domesticus	ARG	93
7	0405 Butter, incl. dehydrated butter and ghee, and other fats and oils derived from milk; dairy spreads	NZE	78
8	04051019 Natural butter of a fat content, by weight, of >= 80% but <= 85% (excl. in immediate packings of a net content of <= 1 kg, and dehydrated butter and ghee)	NZE	72
9	0201+0202 Meat of bovine animals, fresh, chilled, frozen	ARG	58
10	0406 Cheese and curd	CHE	44

The three most important import flows are sheep meat from New Zealand, beef from Brazil and chicken from Brazil (see also GGELS 1st interim report). Thus, the analysis is carried out for the products presented in bold in the table (numbers 2, 3 and 4). These are typically primary animal products, and allocation of all the food chain emissions to these meat products covers partly also emissions of the products in categories 1 and 5.

The emissions considered for these products are presented in Table 9.2. This approach does not include the emissions from meat processing[26] or capital in the farms (e.g. vehicles, machinery, farm buildings, fences, water supply), which are outside the boundaries of the food chain approach defined in this chapter. Emissions due to fossil fuel manufacture, or indirect emissions related to electricity production are also excluded.

A brief analysis of the main production characteristics of the main animal products imported to the EU has been carried out for assessing the GHG emissions from a food chain perspective induced by these products.

[26] It is stated in the TOR of GGELS that "Emissions from processing and refrigeration of animal products will not be covered, so as not to lengthen the study."

Table 9.2: 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

9.2.2. Sheep meat from New Zealand

9.2.2.1 Production characteristics

According to Eurostat, **191kton** of sheep meat[27] were imported by the EU from New Zealand in 2007, classified under category '0204 Meat of sheep or goats, fresh, chilled or frozen'. Inclusion of also goat meat in the same category is not likely to cause noticeable bias in the estimates as imports are small and goat population is about 0.4% of the total goat and sheep population in New Zealand (Emission Database for Global Atmospheric Research, EDGAR; FAOSTAT, 2008).

The average sheep stock in New Zealand between 2000 and 2005 was 40,090 thousand heads, whereas the average number of animals slaughtered per year was 29,996 thousand heads in the same period (FAOSTAT, 2008). This indicates that the annual average sheep stock is **1.34** times the number of sheep slaughtered for meat production.

According to ABARE and MAF (2006), the number of sheep slaughtered for export in 2004-2005 (July-June) was about 24.6 million head, and the product exports were 295 kton. Consequently, the average meat production would be **12 kg/head**, whereas the average carcass weight is 17.4 kg. The carcass weight is of the same magnitude as reported in FAOSTAT (2008).

[27] The categorization of Eurostat groups sheep meet together with goat meat.

Table 9.3: Main production characteristics of sheep from New Zealand.

Item	Value	Unit
Sheep meat imports from NZE to EU	191	kton
Average sheep stock in NZE 2000-2005	40090	thousand heads/a
Average number of heads slaughtered 2000-2005	29996	thousand heads/a
Average carcass weight	17	kg/head
Average meat production	12	kg/head
Average pastureland used	0.157	ha/head/a

In New Zealand, all sheep are in pasture (Ministry for the Environment, 2008; Saggar et al., 2007). Thus there are no emissions related to feed production or transportation, manure management, manure application to soils or animal housing. It is also assumed that no land-use change is occurring in New Zealand due to grazing.

According to Saggar et al. (2007), sheep grazing occupies 7.1 million hectares. However, based on data from Statistics New Zealand (2008), sheep and cattle farming is often practiced together, and sheep can be found in almost any type of farm (Table 9.4). In the agricultural statistics of New Zealand, the land-use by farm type is divided into the following subcategories: (1) Grassland, (2) Tussock and danthonia used for grazing (whether oversown or not), (3) Grain, seed and fodder crop land, and land prepared for these crops, (4) Horticultural land and land prepared for horticulture, (5) Plantations of exotic trees intended for harvest, (6) Mature native bush, (7) Native scrub and regenerating native bush, and (8) Other land. All these land uses are occurring in sheep farms (e.g. category ‘sheep farming (specialized)’). For the purposes of this study, only land-use categories (1) and (2) are considered, as they are assumed to represent the grazing land of sheep, whereas other land uses are assumed to be primarily used for other farm activities.

Table 9.4: Sheep numbers and farm area by farm type in 2007 (Statistics New Zealand, 2008).

Importance	Farm type (ANZSIC06)	Total sheep	Grassland (ha)	Tussock and danthonia used for grazing (ha)	Cumulative share of sheep
1	**A0144 Sheep-beef cattle farming**	**19,874,190**	**3135493**	**1229761**	**51.7%**
2	**A0141 Sheep farming (specialised)**	**14,815,823**	**1598446**	**1339470**	**90.2%**
3	**A0142 Beef cattle farming (specialised)**	**925,430**	**983588**	**196143**	**92.6%**
4	A0145 Grain-sheep and grain-beef cattle farming	680,905	62570	0	94.4%
5	A0180 Deer farming	521,572	229772	75086	95.7%
6	A0160 Dairy cattle farming	382,677	1742242	13297	96.7%
7	A0149 Other grain growing	361,309	24113	1251	97.7%
8	A0123 Vegetable growing (outdoors)	301,014	34030	369	98.4%
9	A0301 Forestry	190,566	83387	24180	98.9%
10	A0159 Other crop growing nec	99,924	62920	4811	99.2%
11	A0131 Grape growing	68,954	14921	1970	99.4%
12	A0199 Other livestock farming nec	42,549	19587	0	99.5%
13	A0112 Nursery production (outdoors)	35,284	3843	88	99.6%
14	A0192 Pig farming	34,246	12460	189	99.7%
15	A0134 Apple and pear growing	26,432	3874	0	99.7%
16	A0191 Horse farming	26,414	41213	205	99.8%
17	A0133 Berry fruit growing	15,015	2264	0	99.8%
18	A0135 Stone fruit growing	12,380	2458	321	99.9%
19	A0132 Kiwifruit growing	9,675	6970	31	99.9%
20	A0136 Citrus fruit growing	7,245	1849	0	99.9%
21	A0139 Other fruit and tree nut growing	6,247	5104	160	99.9%
22	A0115 Floriculture production (outdoors)	3,128	846	0	99.9%
23	A0172 Poultry farming (eggs)	2,260	0	0	100.0%
24	Other	1,987	4851	0	100.0%
25	A0114 Floriculture production (under cover)	970	721	0	100.0%
26	A0137 Olive growing	737	513	0	100.0%
27	A0111 Nursery production (under cover)	227	227	0	100.0%
	TOTAL New Zealand	**38,460,477**	**8080900**	**2887332**	

The cumulative share of sheep in different farm types is presented in Table 9.4. For the purposes of this study, the three most important farm types are chosen to represent the grazing practice in New Zealand.

In the case of farming of both beef cattle and sheep, the area of grazing land has to be divided between the two animal types. According to the National Inventory Report of GHG emissions of New Zealand to the UNFCCC (Ministry for the Environment, 2008), all sheep and beef cattle are fed in pasture. In this study, the area needed by head is divided between sheep and beef cattle by using the livestock units, i.e. assuming that for example an adult beef cow needs six times as much feed (in this case, grazing land) as sheep (Barber & Lucock, 2006). Based on the data, the average area of grazing land for sheep is **0.157 ha/head**.

9.2.2.2 Estimation of emissions from different sources

Fertilizer manufacture and use

Statistics New Zealand also provides data on the use of fertilizers in each farm type. In the calculation of average N input per hectare, we first leave out land uses ‘Mature native bush’, ‘Native scrub and regenerating native bush’ and ‘Other land’ assuming that no fertilizers are applied to these lands. By leaving these land types out, grasslands cover 96-97% of total area in the three farm types. Therefore crop cultivation is not assumed to cause bias to the estimated fertilizer application rates. By estimating also the average N contents of each fertilizer type, we obtain an average N fertilizer application rate of **7.6 kg N/ha grazing land**. The ARGOS study (Barber & Lucock, 2006) that was based on a small sample of farms reports the following N fertilizer application rates: 0 for organic, 11.1 for integrated and 8.6 kg N/ha for conventional sheep and beef farms without crops.

Based on the same statistics, use of urea (included in the N fertilizer numbers) is **9.6 kg urea/ha**, and use of lime **92 kg/ha**.

The emission factors for fertilizer and lime use are presented in Table 9.5. Emission factors are from the EDGAR database, and are based on IPCC methods and scientific literature. The NH_3 emission factor is calculated based on an average fertilizer mix used in New Zealand between 2000 and 2005 (IFA, 2007).

Table 9.5: Emission factors for fertilizer and lime use (IPCC, 2006; EDGAR).

Type	**Emission compound**	**Emission factor**
N fertilizer use	N_2O	0.0157 kg N_2O/kg N
N fertilizer use	NH_3	0.23 kg NH_3/kg N
Urea use	CO_2	3.67 kg CO_2/kg C in urea
Lime use	CO_2	0.44 kg CO_2/kg limestone

The emission factors for N fertilizer manufacture are based on a review of Wood & Cowie (2004). The emission factors, expressed as $CO_{2\text{-eq}}$, include CO_2 emissions from ammonia production, N_2O emissions from nitric acid production and CO_2 emissions from energy use for fertilizer production. The emission factors used here are averages of emission factors presented as “European average”. For the fertilizer types for which no information was available, emission factors of CAPRI are used. The emission factors used for each fertilizer type are presented in Table 9.6.

Table 9.6: Emission factors for fertilizer manufacture.

Fertilizer type	Emission factor	Source
Ammonium phosphate	6047kg $CO_{2\text{-eq}}$/ton N	CAPRI
Ammonium sulphate	6047kg $CO_{2\text{-eq}}$/ton N	CAPRI
Calcium Ammonium nitrate	7175kg $CO_{2\text{-eq}}$/ton N	Wood & Cowie
Compound NPK-N	5287kg $CO_{2\text{-eq}}$/ton N	Wood & Cowie
Urea	2351kg $CO_{2\text{-eq}}$/ton N	Wood & Cowie
Ammonium nitrate	6854kg $CO_{2\text{-eq}}$/ton N	Wood & Cowie
Compound NK-N	6047kg $CO_{2\text{-eq}}$/ton N	CAPRI
Phosphate fertilizers	2261 kg $CO_{2\text{-eq}}$/ton P_2O_5	CAPRI
Potassium fertilizers	326 kg $CO_{2\text{-eq}}$/ton K_2O	CAPRI

The average emission factor for N fertilizer production in New Zealand – based on average mix of fertilizers used – is **3153 kg $CO_{2\text{-eq}}$/ton N**.

For the production of phosphate and potassium fertilizers, we use emission factors from CAPRI (Table 9.6). The phosphate application rate, leaving out the N containing phosphate fertilizers, is calculated at 18 kg P_2O_5/ha and thus the emission factor is **41.2 kg $CO_{2\text{-eq}}$/ha**[28].

According to IFA (2007), the potassium fertilizers used in New Zealand (those not containing N) are potassium chloride (95%) and potassium sulphate. The use of these in New Zealand sheep farms accounts for 1 kg K_2O/ha, and based on the emission factors in Table 9.6, the emissions are **0.34 kg $CO_{2\text{-eq}}$/ha**.

The CO_2 emission factors for sulphur and agrichemical application are taken from Saunders et al. (2006), and are **7.9** and **8.3 kg CO_2/ha**, respectively. The emissions due to lime manufacture are **0.43 kg CO_2/kg lime**.

Enteric fermentation

The emission factor for enteric fermentation, **11 kg CH_4/head,** is based on the national GHG inventory of New Zealand (Ministry for the Environment, 2008). It is higher than the estimate in EDGAR, 8 kg CH_4/head, which is based on IPCC (2006) default for industrial countries.

[28] Excluding P_2O_5 fertilizer containing nitrogen

Manure management

The national GHG inventory report gives an estimate of nitrogen excretion in pasture of **15 kg N/head** (average over the years 2000-2005), which is used in this study. This coefficient is slightly higher than the 2000-2005 average in EDGAR, 14 kg N/head.

The emission factors for manure excreted in pasture are based on EDGAR and presented in Table 9.7.

Table 9.7: Emission factors for manure excreted in pasture.

Emission factor	**unit**
0.0157	kg N_2O/kg N excreted
0.049	kg NH_3/kg N excreted
0.11	kg CH_4/head

Indirect N_2O

Indirect emissions due to leaching and runoff of fertilizer and manure N are estimated based on EDGAR approach. The emission factor is **1.77 kg N_2O/ton N**. In addition, the deposition of NO_x and NH_3 emissions causes indirect N_2O emissions. The emission factors from EDGAR are **0.0048 kg N_2O/kg NO_x** and **0.013 kg N_2O/kg NH_3**. However, only the indirect emissions from NH_3 are included in this study.

On-farm energy use and meat transportation

According to Saunders et al. (2006), CO_2 emissions from diesel and electricity use allocated to sheep in mixed cattle and beef farms are 46.5 and 2.2 kg CO_2/ha, respectively. However, they consider mixed beef and sheep farms and allocate 47% of emissions per area to sheep. Thus, the following emission factors are used in this study: **98.9 kg CO_2/ha** for diesel and **4.7 kg CO_2/ha** for electricity.

Emissions from ocean transport of sheep meat are estimated based on the approach used by FAO (2006), which excluded road transport. As the report did not include transportation from New Zealand to Europe, it is assumed that the vessels and related parameters are similar to the ones used to transport cattle meat from New Zealand to USA. The distance between New Zealand and EU is set to 18 000 km (**9719 nautical miles**) based on Saunders et al. (2006). Thus the emission due to transportation is **73.2 kg CO_2/t** meat.

9.2.2.3 Total GHG emissions

The emissions are allocated between the market value of different products, which in the case of sheep are meat, edible offal and wool. According to Chapagain & Hoekstra (2004), the value fraction of sheep meat is **81%**, which is used in this study. This is in line with the study of Sainz

(2003), according to which the share of emissions allocated to sheep meat varies between 57 and 84%.

The calculated emissions per ton of meat are presented in Table 9.8 and the contribution of each source to the $CO_{2\text{-eq}}$ emissions in Figure 9.2. The GWP values used are 21 for CH_4 and 310 for N_2O.

Table 9.8: Emissions of sheep meat imported from New Zealand to EU (per kg of meat and per total imports to the EU). CO_2 and N_2O emissions from fertilizer production could not be separated as the data source used gives emission factors as $CO_{2\text{-eq}}$

Compound	**Emissions by substance**	**Total emissions of imported meat in 2007**	**Share of GHG emissions**
CO_2 without fertilizer production	3.0 kg CO_2/kg meat	575 kton CO_2 eq	9%
CO_2 + N_2O from fertilizer production	0.9 kg $CO_{2\text{-eq}}$/kg meat	178 kton CO_2 eq	3%
CH_4	1.0 kg CH_4/kg meat	4047 kton CO_2 eq	63%
N_2O without fertilizer production	0.03 kg N_2O/kg meat	1582 kton CO_2 eq	25%
GHGs	**33 kg $CO_{2\text{-eq}}$/kg meat**	**6382 kton CO_2 eq**	
NH_3	**0.1 kg NH_3/kg meat**	**17 kton NH_3**	

The most important GHG emission sources are enteric fermentation (63% of $CO_{2\text{-eq}}$ emissions) and manure excreted in pasture (20%). Indirect emissions from leaching and runoff of manure N accounts for additional 2%. On-farm energy use accounts for 4%, and the rest of the sources for less than 2% each. Regarding NH_3 emissions, 73% is from manure in pasture, and the rest from N fertilizer application.

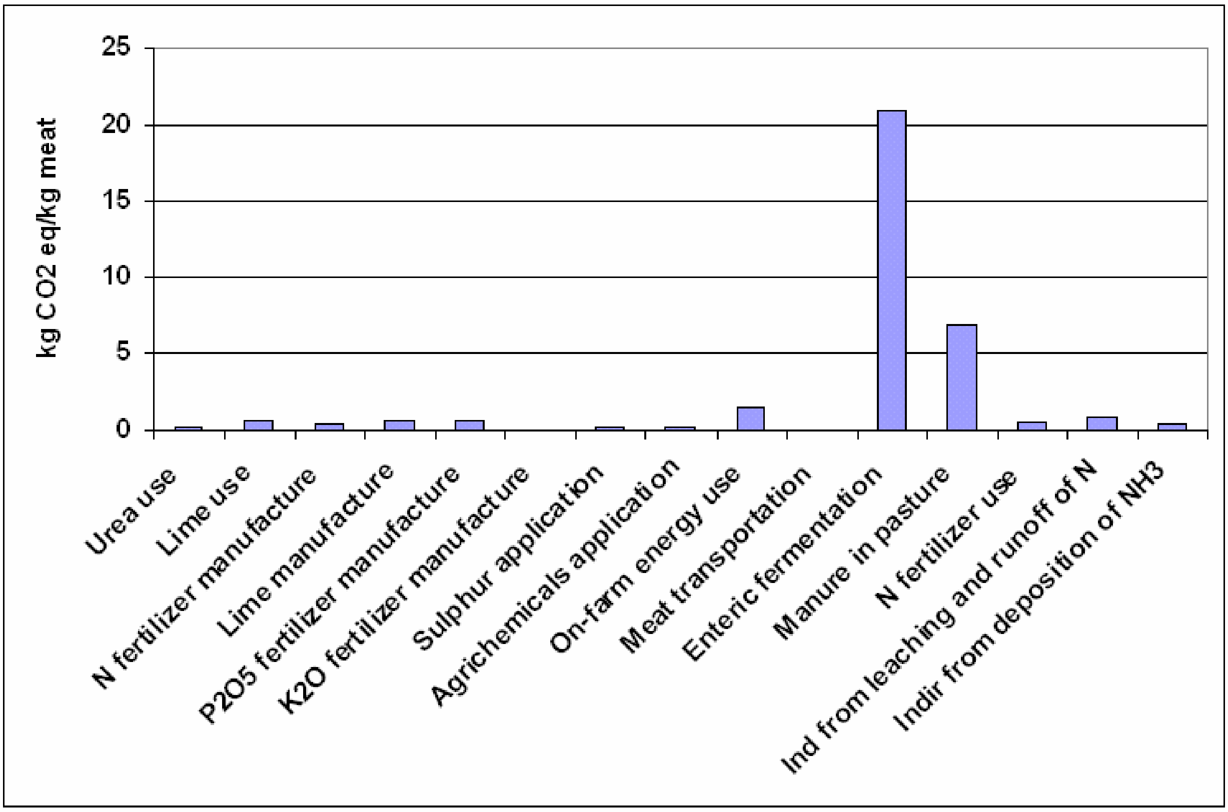

Figure 9.2: Contribution of different emission sources to the $CO_{2\text{-}eq}$ emissions of sheep meat imported to the EU.

9.2.3. Beef meat from Brazil

9.2.3.1 Production characteristics

The export share of Brazilian beef is on the rise, but still represents only some 10% of national production. We can thus assume that EU beef imports from Brazil originate from (central and eastern) South Brazil, an important beef production area where slaughterhouse density is highest, located near the main harbours. Beef meat import to EU from Brazil in 2007 was **180 kton** based on Eurostat category ‘Meat of bovine animals, fresh, chilled’ (80 kton) and ‘Meat of bovine animals, frozen’ (100 kton).

Cattle farming in Brazil is almost entirely based on grazing (Carvalho, 2006; IPCC, 2006), and according to FAO (2006) fertilizer use in pasture in Brazil is negligible. Therefore, the emissions from animal housing, feed production and manure management are negligible[29]. In addition, on-farm energy use can be neglected, as there is no housing and no fertilizer application which usually

[29] The study of Cederberg et al. (unpublished) also includes only pasture-based production, but it is mentioned that feedlot systems have been introduced in Brazil and represent a minor but increasing fraction of beef production.

represent a major share of the energy use. The pasture stocking rate is about **0.9 head/ha** annually (Carvalho, 2006).

The sheer exclusive dependence of bovine feeding on pastures makes seasonal lack of feed the main factor explaining the rather low productivity (a slaughter weight between 400 and 480 kg, but a long production cycle of 5 to 7 years) (Embrapa, 2003). The legume ratio in pastures is low, limiting digestibility and thus productivity (while increasing methane from enteric fermentation) (Carvalho, 2006). Carvalho (2006) reports a reduction of herd age to slaughter over the last decade that would now be around 4 years. He also states that the absence of pasture fertilization leads to increasing pasture degradation. Although this might lead to significant soil carbon loss, lack of data impeded us from further considering this issue.

Feedlots exist and increase in importance, but still represent only some 1% of the total Brazilian production. Fattening and finishing are also largely pasture based. Indoor feeding occurs in the dry period and for unweaned claves, but even here feeding is grass silage and cane residue based (Embrapa, 2003). The value fraction of cane residue is low, so little land can be attributed to this use, which is anyway a long standing, rather stable production involving little greenhouse gas emissions. Despite the important Brazilian maize production, no significant amounts of maize are reported to be used as fodder, so no additional land use will be considered.

Average carcass weight of cattle in Brazil was **213 kg** (FAOSTAT) in the 5-year period 2003-2007. Based on USDA report (Silva, 2007), total meat, beef and veal exports from Brazil were 1945 kton carcass weight equivalent in 2006, whereas exports were 1431 kton as meat. This would give a conversion factor of 0.735 from carcass to exported meat, and thus a meat yield of **156 kg/head**. The conversion factor used here is in a good accordance with the value used by Cederberg et al. (unpublished), 0.70.

In the period 2000-2005, average non-dairy cattle stock in Brazil was 170.4 million of heads (FAO data in EDGAR). In the same period, on average 35.1 million heads were slaughtered for cattle meat in Brazil. The slaughter statistics include both dairy and beef cattle. The share of dairy cattle in Brazil is about 10% of the total cattle stock, and if we assume that the lifetime of dairy cattle is twice the lifetime of beef cattle, we can allocate 5% of the slaughters to dairy cattle. Based on this data we can calculate that the annual average beef cattle stock is approximately **5** times the number of animals that are slaughtered[30]. Thus the meat production per head in living stock is 31 kg/head, which is in agreement with FAO (2006), according to which beef production per animal in grazing systems is 36 kg/head and year globally and 29 kg/head and year in developing countries.

[30] According to Cederberg et al. (unpublished) share of slaughtered cattle to total population in Legal Amazon is 0.19 and for the rest of Brazil 0.25.

Table 9.9: Most important production characteristics of beef from Brazil.

Item	Value	Unit
Beef meat imports from Brazil to EU	180	kton
Average beef stock in Brazil 2000-2005	170	million head
Average number of heads slaughtered 2000-2005	35	million head
Average carcass weight	213	kg/head
Average meat yield	156	kg/head
Pasture stocking rate	0.9	head/ha

9.2.3.2 Estimation of emissions from different sources

Fertilizer manufacture and use

According to FAO (2006) fertilizer use in pasture in Brazil is negligible. Cederberg et al. (unpublished) estimate that in cultivated pastures, fertilizer application rate is 4 kg/ha as P_2O_5 content of single superphosphate. If we assume that 60% of the pastures are cultivated, the average fertilizer application rate is **2.4 kg/ha** grassland. The emission factor used for fertilizer manufacture is reported in Table 9.6.

Enteric fermentation

The emission factor for enteric fermentation is **60.7 kg CH_4/head** based on EDGAR. FAO (2006) applies an emission factor of 57.9 kg CH_4/head for grazing beef cattle in Central and South America, and in the National Communication of Brazil to the UNFCCC (Ministry of Science and Technology, 2004), the emission factor for 1990-1994 is 55.8 kg CH_4/head.

Manure in pasture

The emission factors for manure deposition in pasture are taken from EDGAR (Table 9.10), and compared with the estimates of FAO (2006) for Central and South America (weighted averages across different production systems).

Table 9.10: Emission factors for manure in pasture from EDGAR and FAO (2006).

Compound	EDGAR (average 2000-2005), kg/head	FAO (2006) kg/head
CH_4	1	0.98
N_2O	1.27	1.14
NH_3	4.0	

Indirect N_2O

The emission factors for indirect emissions due to leaching and runoff of manure N and that for atmospheric deposition of NH_3 are the same as in the case of New Zealand[31].

Land-use change

There is evidence that deforestation in tropical regions is partly driven by the need to expand pastures for grazing livestock. In Brazil, most of the recent growth in cattle herd has taken place in the Legal Amazon[32], where deforestation mainly occurs for expansion of grazing land (McAlpine et al., in press; Cederberg et al., unpublished). Based on FAOSAT/COMTRADE data and Cederberg et al. (unpublished), beef consumption in Brazil has remained relatively stable over the last years, whereas beef production has increased together with increasing exports. Therefore, the pasture expansion could be attributed to export products (while ignoring displacement of beef pasture by elsewhere expanding dairy production)[33].

On the other hand, Cederberg et al. (unpublished) also point out that beef production in Legal Amazon has contributed little to exports by 2006, whereas the most important beef-exporting states of Brazil have traditionally been situated in the southern and central-western parts of the country. However, in 2006 the share of export value of beef produced in Legal Amazon grew to 22% and further to 24% in 2007. The growth can be partly explained by the outbreak of foot-and-mouth disease and followed bans for some of the states that were important exporters before.

Pasture area in Legal Amazon has increased from 51.2 Mha to 61.6 Mha between 1995 and 2006, whereas the meat production as carcass weight equivalent has increased from 1.096 to 2.021 million tons between 1997 and 2006. This means that an increase of carcass weight production by ton has required on average 9.2 ha additional grazing land, and, consequently, increase of meat production by ton has required additional 12.5 ha grazing land[34]. Following the IPCC (2006) method, the emissions from land use change are calculated for a period of 20 years, and therefore to estimate the emissions occurring in 2006, deforestation between 1987 and 2006 has to be considered.

From 2000 to 2006, the beef meat imports to Europe have increased by an average rate of 29000 ton/year. Cederberg et al. (unpublished) present the export of beef from Legal Amazon and other regions in Brazil for the years 1996-2006, showing an increasing trend in exports from Legal Amazon. If we assume that the EU exports follow the same trend (i.e. increasing share originating from Legal Amazon), the average increase in the exports from Legal Amazon is 2300 ton/year. If we conservatively assume that this same increase rate occurred also from 1998 to 2000 (as before that there were no exports from Legal Amazon), the average increase in exports between the 20 year time period 1987-2006 would be 940 ton/year, which would mean, by using the average land

[31] In EDGAR calculations, the average emission factor for leaching and runoff in Brazil is somewhat lower than that of New Zealand due to non-irrigated dryland regions in which leaching and runoff are assumed not to occur. However, export products are not estimated to be produced in these regions.

[32] The largest socio-geographic division of Brazil, which contains all of its territory in the Amazon Basin. It is officially designated to encompass all seven states of the North Region (Acre, Amapá, Amazonas, Pará, Rondônia, Roraima and Tocantins), as well as Mato Grosso state in the Center-West Region and most of Maranhão state in the Northeast Region.

[33] This may look like a strong assumption, but even if it is likely to be not far off from the truth, it’s strength is much weakened by the accompanying assumption that EU imports originate uniformly from all Brazilian beef pasture area, resulting in a small portion originating from the deforested area.

[34] Note that other changes in beef productivity occurred simultaneously in Legal Amazon.

requirement of 12.5 ha/ton of meat, deforestation rate of 11 thousand ha/year[35] for exports to the EU.

According to FAO (2006), the carbon losses due to forest conversion to grassland are 605 t CO_2/ha and 117 t CO_2/ha in plants and soil, respectively, based on difference in the carbon stocks of forest and grassland[36]. Cederberg et al. (unpublished), instead, calculate the 'net committed emissions[37]'and arrive at an estimate of 568 t CO_2 eq/ha of carbon losses. We use this estimate in our study.

On-farm energy use and meat transportation

The on-farm energy use in beef production in Brazil is minor, as there is practically no housing of animals and fertilizer application occurs only to a small extent. The study of Cederberg et al. (unpublished) estimated that cultivated pastures are renovated every ten years, and that the fuel use for this purpose is **12 litres diesel/ha**. We use this estimate, together with IPCC (2006) default NCV of **43 TJ/Gg** and emission factor of **74.1 t CO_2/TJ**, and estimated diesel density of **0.85 kg/l**.

Emissions from transatlantic transportation of beef are estimated based on the approach of FAO (2006), again ignoring prior and post road transportation. The emissions from transportation of beef are **68.8 kg CO_2/t meat.**

9.2.3.3 Total GHG emissions

According to Chapagain & Hoekstra (2004), the beef carcass represents about **87%** of the live animal's value. The rest of the value comes from offal and hide. Consequently, 87% of the emissions are allocated to meat.

The total GHG emissions per ton of meat are presented in

Table 9.11, and contribution of each factor to total emissions in Figure 9.3. The GHG emissions are estimated at 80 kg CO_{2-eq}/kg meat including emissions from land use changes (LUC) and 48 kg CO_{2-eq}/kg meat excluding emissions from LUC.

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[35] This estimate depends largely on the years chosen for consideration. For example, the imports to EU dropped in 2007, and the average import growth rate from 2000-2007 would have been -830 ton, and following the method presented above we would not have allocated any emissions to deforestation. Total beef imports from Brazil to EU declined further in 2008 because of bans due to deficiencies in the Brazilian cattle identification and certification system and in the Brazilian government oversight and testing (Cederberg et al., unpublished). Another important factor is that we are not able to identify whether deforestation in Legal Amazon occurs also due to relocation of domestic production to Legal Amazon as a result of increased exports from other parts of the country (indirect land use change). This could explain why the animal herds have increased more in Legal Amazon than exports from that region. In a more detailed life-cycle analysis, also these indirect land-use changes should be taken into account.
[36] The data are based on IPCC Third Assessment report (IPCC, 2001, p. 192).
[37] 'net committed emissions' method calculates emission as a result of the net difference in carbon stock between original and replacing vegetation. The typical cycle is assumed to include phases of clearing, cultivation, grazing and secondary forest re-growth, including also burning.

Table 9.11:Total GHG emissions per ton of meat

Compound	Emission per kg meat	Total emissions of imported meat in 2007	Share of total emissions
CO_2 without fertilizer production	31 kg CO_2/kg meat	5651 kton CO_2 eq	39%
CO_2 + N_2O from fertilizer manufacture	0.2 kg $CO_{2\text{-}eq}$/kg meat	30 kton CO_2 eq	0.2%
CH_4	1.7 kg CH_4/kg meat	6506 kton CO_2 eq	45%
N_2O without fertilizer production	0.04 kg N_2O/kg meat	2170 kton N_2O	15%
GHGs	80 kg $CO_{2\text{-}eq}$/kg meat	14357 kton CO_2 eq	
GHGs without deforestation	**48 kg $CO_{2\text{-}eq}$/kg meat**	**8733 kton $CO_{2\text{-}eq}$**	
NH_3	**0.11kg NH_3/kg meat**	**20 kton NH_3**	

The total GHG emissions are dominated by two factors: enteric fermentation (45%) and land-use change (39%). The emissions from manure in pasture account for 15%, and the rest of emissions sources are negligible.

The only NH_3 emission source is manure from pasture.

Our estimates of emissions from enteric fermentation per unit of meat are about 20% higher than those of Cederberg et al. (unpublished), mainly due to the differences in estimated age structure of the herd and lifetime of an animal before slaughter, which are uncertain factors and vary largely between different regions in Brazil.

The estimates of land use change triggered by livestock production are the most uncertain ones in this study. A precise allocation of emissions from land use change to exported beef is a challenging task, and no agreed methodology and accurate data exists. This chapter presents a simplified approach, and the results should be used with extreme caution.

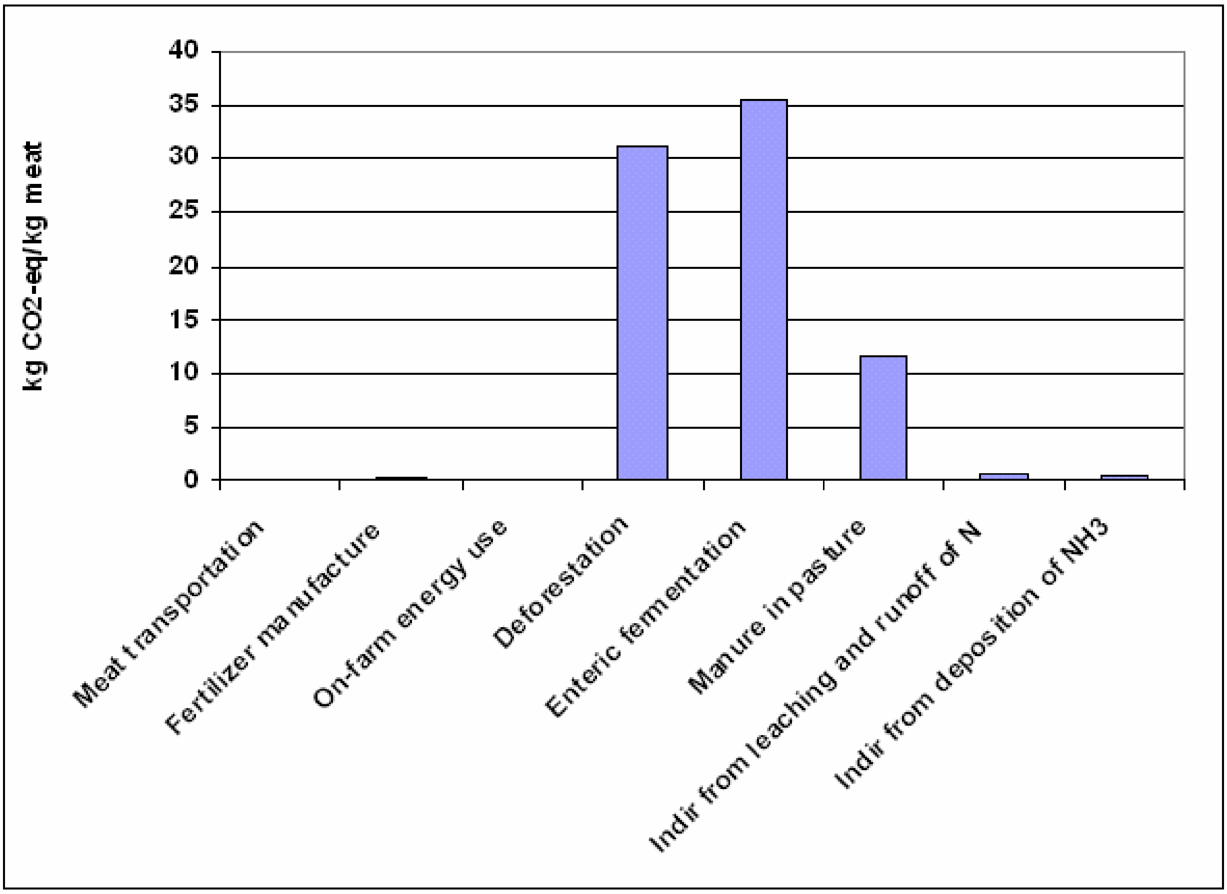

Figure 9.3: Contribution of each emission source to $CO_{2\text{-}eq}$ emissions from beef imported to the EU from Brazil.

9.2.4. Chicken meat from Brazil

9.2.4.1 Production characteristics

According to Eurostat, poultry meat[38] imports to the EU from Brazil were **170 kton** in 2007. According to EDGAR, chicken represent a share of 98% of the population of chicken, turkeys and ducks in Brazil, and therefore the poultry imports are used to represent chicken meat imports from Brazil.

The chicken meat imported to EU is assumed to come entirely from the intensive systems in Southern Brazil. The feed consumption/head is estimated to be **1.7** times live weight at slaughter, which is assumed to be **1.9 kg** as in the CAPRI model.

The five-year (2003-2007) average carcass weight of chicken in Brazil is **1.55 kg/head** (FAOSTAT) and therefore 109.5 million heads are needed to produce the meat imported to Europe.

[38] Meat and edible offal, of the poultry (Gallus domesticus, ducks, geese, turkeys and guinea fowls), fresh, chilled or frozen

If we assume that broilers are alive for 60 days, the average annual stock needed for meat imports is 18 million heads. The total population (109.5 million) is used to calculate emissions related to feed production, whereas the average annual population (18 million) is used to calculate emissions from manure management.

Table 9.12:Most important production characteristics of chicken from Brazil.

Item	Value	Unit
Chicken meat imports from Brazil to EU	170	kton
Estimated lifetime	60	days
Average carcass weight	1.55	kg/head
Feed consumption	3.23	kg/head

9.2.4.2 Estimation of emissions from different sources

Feed production, including fertilizer production and use

Table 9.13 presents parameters related to chicken feed. According to FAO (2006, p. 43), soybeans yield 18-19% oil and 73-74% soy meal, which thus is a by-product of soybean oil industry. Chapagain and Hoekstra (2004) allocate 34% of the value to crude oil of soybeans, and therefore we allocate 66% of the emissions from soybean cultivation to soy meal. The share of "other" is dealt as a weighted average of wheat, soy meal, sorghum and maize.

Feed imports to Brazil are considered negligible, as the domestic production of all the four feed crops is higher than consumption as feed based on FAO Supply Utilisation Accounts and Food Balances statistics (FAOSTAT, 2008).

Table 9.13: Chicken feed composition in Brazil (FAO, 2006, p. 41), average yield of crops (FAOSTAT) 2000-2005, average N fertilizer use by crop (FAO/IFA), and N in crop residues left to soils (EDGAR).

Crop	Share of feed	Yield (kg/ha)	Fertilizer use			Crop residues
			kg N/ha	kg P_2O_5 /ha	kg K_2O /ha	(kg N/ha)
Wheat	2%	1905	80	40.0	60.0	20
Soy meal	24%	2524	10	50.0	60.0	26
Sorghum	1%	1978	60	30.0	40.0	16
Maize	66%	3223	60	30.0	50.0	21
Other	7%					

The N_2O emission factor for N fertilizer use and the CO_2 emission factor for urea use are the same as used for sheep from New Zealand. However, the NH_3 emission factor is **0.19 kg NH_3/kg N** based on fertilizer mix in Brazil and EDGAR NH_3 emission factors. The national fertilizer mix is based on IFA (2007), and the share is assumed to be the same for each of the feed crops.

There is no detailed data on lime use in Brazil by crop. However, Bernoux et al. (2003) estimated that a mean CO_2 flux due to liming of soils is 3.96 g/m^2 in Southern Brazil and 3.33 g/m^2 in South-eastern Brazil. We use an average of **3.65 g CO_2/m^2** to estimate the emissions from liming related to feed production.

The emission factors for fertilizer and lime manufacture are the same as used in the case of sheep from New Zealand (Table 9.6). Due to lack of data, we neglect the other chemicals that may be applied to soils.

The emission factors for crop residues left in soils are based on EDGAR approach, and are **0.012 kg NH_3/kg N** and **0.0157 kg N_2O/kg N**.

Manure management

CH_4 emissions from manure management are estimated based on the IPCC (2006) emission factor for broilers: **0.02 kg CH_4/head**. The nitrogen excretion rate is also based on IPCC (2006), and is **0.36 kg N/head**.

Table 9.14 presents emission factors for manure management and manure application to soils. It is assumed that all chicken manure is use to fertilize the crops used as feed.

Table 9.14: N_2O and NH_3 emission factors for manure management and manure application to soils based on EDGAR.

Category	Emission factor	Unit
Manure management	0.00157	kg N_2O/kg N excreted
Manure management	0.364	kg NH_3/kg N excreted
Manure applied to soils	0.006	kg N_2O/kg N excreted
Manure applied to soils	0.124	kg NH_3/kg N excreted

Land-use change

According to FAOSTAT/COMTRADE data, the chicken meat exports from Brazil to the EU increased between 2003 and 2005 and decreased thereafter, being lower in 2007 than 2003. Due to this development, we do not allocate emissions from deforestation to chicken meat, as in average the exports to Europe have not required extension of cropland for feed production.

On-farm energy use and meat transportation

The on-farm energy use and related CO_2 emissions from intensive systems are estimated based on data in CAPRI on chicken meat imported to the EU: **31.25 MJ/kg carcass.**

The emission factor for chicken meat transport from Brazil to Europe is the same as for beef.

9.2.4.3 Total GHG emissions

In the case of chicken, all emissions are allocated to meat.

The calculated emissions per ton of meet are presented in Table 9.15, and contribution of each of the factors to GHG emissions in Figure 9.4.

Table 9.15: Emissions from chicken meat imported from Brazil to EU (per kg of meet). CO_2 and N_2O emissions from fertilizer production could not be separated as the data source used gives emission factors as CO_{2-eq}

Compound	Emission	Total emissions of imported meat in 2007	Share of total GHG emissions
CO_2 without fertilizer production	0.55 kg CO_2/kg meat	94 kton CO_{2-eq}	44%
CO_2 + N_2O from fertilizer production	0.19 kg CO_{2-eq}/kg meat	33 kton CO_{2-eq}	16%
CH_4	0.00 kg CH_4/kg meat	8 kton CO_{2-eq}	4%
N_2O without fertilizer production	0.00 kg N_2O/kg meat	77 kton CO_{2-eq}	37%
GHGs	**1.2 kg CO_{2-eq}/kg meat**	**211 kton CO_{2-eq}**	
NH_3	**0.02 kg NH_3/kg meat**	**4.2 kton NH_3**	

On-farm energy use is the most important source of GHGs (34%) from chicken meat imported to the EU. Use and manufacture of fertilizers account for 28% of GHG emissions, and indirect N_2O emissions for 12%. Manure management and use of manure as fertilizers cause 11% of emissions. Meat transportation is responsible for 6% and crop residues for 5% of emissions.

In the case of NH_3, manure management is the most important emission source (56%) followed by use of nitrogen fertilizers (24%) and application of manure to soils (19%).

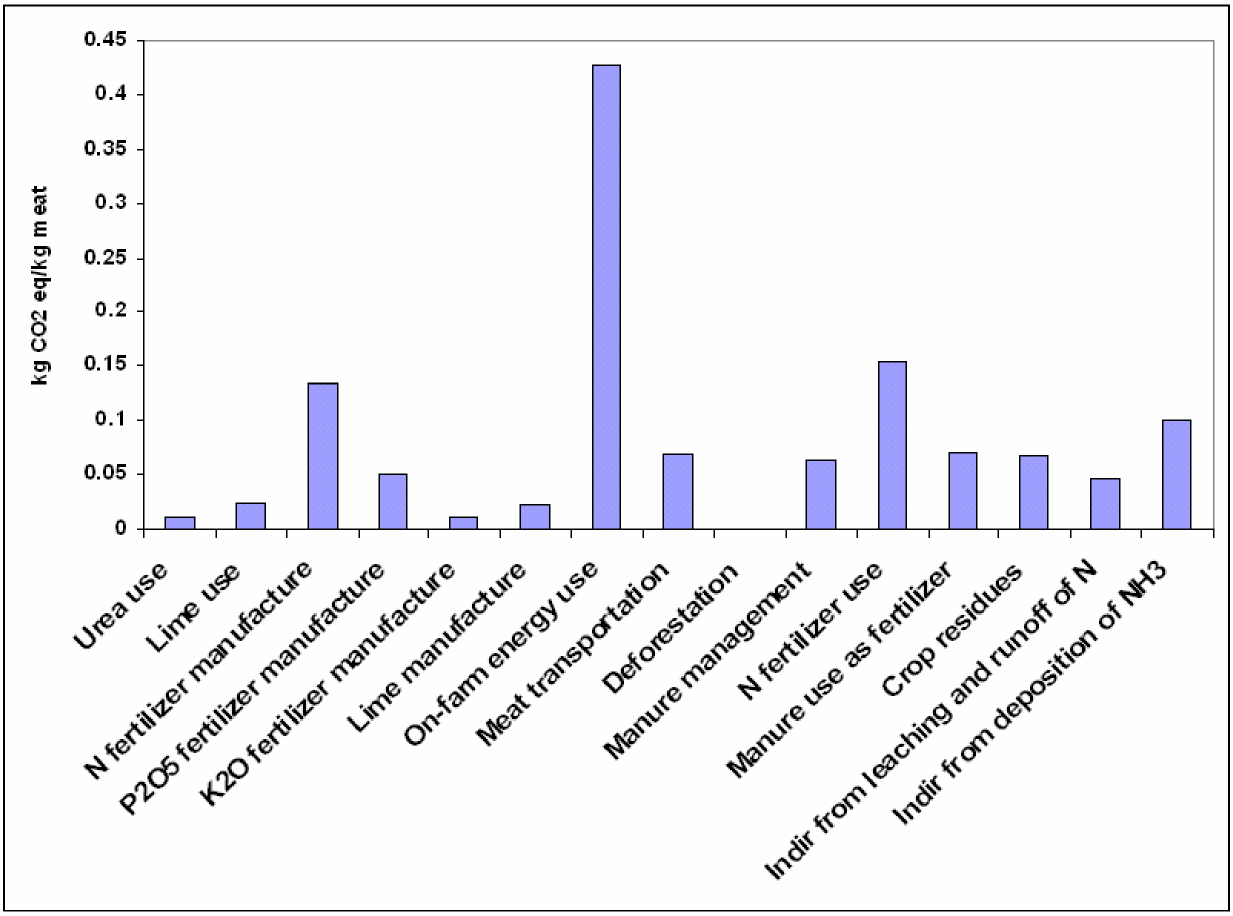

Figure 9.4: Contribution of different emission sources to $CO_{2\text{-}eq}$ emissions from chicken imported to the EU from Brazil.

9.2.5. Conclusions

The emission levels per unit of production (emissions intensity) vary a lot among the three products considered (Table 9.16).

Methane emissions levels of the two ruminant meat products differ mainly because of the less optimal feeding of Brazilian beef cattle compared to New Zealand sheep. Their nitrous oxide emission levels are fairly similar. Direct livestock emissions (from enteric fermentation and manure) strongly dominate all other food chain emissions of these two products. The single very noticeable exception is land use change related to Brazilian beef. Adding this factor takes Brazilian beef emissions from a level of about 1.4 times that of New Zealand sheep to 2.4 times that level.

Compared to the former two, Brazilian chicken GHG emissions are much less significant (about 65 times less that of Brazilian beef). Its emissions are dominated by energy use.

Multiplying the emission intensities with the volume of the import flows the GHG emissions “imported” by the EU through New Zealand sheep meat, Brazilian beef and Brazilian chicken

amount respectively to 6.4, 14.4 and 0.2 million ton CO_2 eq., i.e. a total of 21 million ton CO_2 eq. Compared to all GHG emissions produced within the EU (5143 million ton CO_2 eq. in 2006[39]) this is a rather insignificant amount (0.4%), but it constitutes 4.4% of all agricultural emissions produced in the EU. The essential information which will be provided by GGELS Phase 2 is how this compares to per unit product emissions of the same products but from EU origin.

Table 9.16: 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%)

[39] Total GHG emissions excluding net CO2 emissions from LULUCF

10. 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.

→ 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 $CO_{2\text{-eq}}$

→ 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.

→ 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%).

→ 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-eq}/kg product, while cow milk has the lowest carbon footprint with 1.4 kg CO_{2-eq}/kg.

→ 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-eq}/kg) and the Netherlands (17.4 kg CO_{2-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.

→ 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-eq}/kg are estimated for sheep meat from New Zealand, 80 or 48 kg CO_{2-eq}/kg for beef from Brazil, considering or neglecting emissions from land use change, respectively, and 1.2 kg CO_{2-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.

→ 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-eq}.

→ 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-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).

→ 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.

11. REFERENCES

11.1. References Chapter1 - Introduction

Casey J. W. and Holden N. M. (2005). Analysis of greenhouse gas emissions from the average Irish milk production system. Agric. Syst. 86 (1): 97-114. http://www.sciencedirect.com/science/article/B6T3W-4DXC2SP-5/2/d0229c839871ec7d6fc8d84ee1e493f1

FAO (2006). livestock's long shadow - environmental issues and options, Food and Agriculture Organization of the United Nations: Rome.

FAO (2010). Greenhouse Gas Emissions from the Dairy Sector. A Life Cycle Assessment, Food and Agriculture Organization of the United Nations.

Galloway J., Dentener F., Burke M., Dumont E., Bouwman A. F., Kohn R. A., Mooney H. A., Seitzinger S. and Kroeze C. (2010). The impact of animal production systems on the nitrogen cycle. In: Livestock in a Changing Landscape. Volume 1. Drivers, Consequences and Responses. Steinfeld H., Mooney H., Schneider F., and Neville L. (Editors). Washington, USA: Island Press. p. 83-95.

Garnett T. (2009). Livestock-related greenhouse gas emissions: impacts and options for policy makers. Environmental Science & Policy 12 (4): 491-503. 1462-9011. doi: DOI: 10.1016/j.envsci.2009.01.006

IDF (2009). Environmental/Ecological impact of the dairy sector: Literature recview on dairy products for an inventory of key issues. List of environmental initiatives and influences on the dairy sector. Bulletin of the International Dairy Federation 436.

Stehfest E., Bouwman L., van Vuuren D. P., den Elzen M. G. J., Eickhout B. and Kabat P. (2009). Climate benefits of changing diet. Climate Change 95: 83-102. DOI 10.1007/s10584-008-9534-6.

Steinfeld H. and Wassenaar T. (2007). The role of livestock production in carbon and nitrogen cycles. Annual Reviews of Enironment and Resources 32: 15.1-15.24.

11.2. References Chapter 2 - Overview of the EU livestock sector

Bjornlund, B., N. Cochrane, et al. (2002). Livestock sectors in the economies of Eastern Europe and the Former Soviet Union: Transition from plan to market and the road ahead. Agricultural Economic Report Economic Research Service, U.S. Department of Agriculture: 76.

Bos, J., A. Pflimlin, et al., Eds. (2003). Nutrient management at farm scale. How to attain policy objectives in regions with intensive dairy farming? Quimper, France.

CEAS (2000). The environmental impact of dairy production in the EU: Practical options for the improvement of the environmental impact, Centre for European Agricultural Studies and The European Forum on Nature Conservation and Pastoralism: 176.

Chapagain, A. K. and A. Y. Hoekstra (2004). Water footprints of nations, Volume 2: Appendices. Value of Water Research Report Series. Delft, The Netherlands, UNESCO-IHE: 240.

Chatellier, V. and V. Jacquerie (2004). "La diversité des exploitations laitières européennes et les effets différenciés de la réforme de la PAC de juin 2003." INRA Production Animale 17 (4): 315-333.

EC (2004). Consumption trends for dairy and livestock products, and the use of feeds in production, in the CEE Accession and Candidate countries. Luxemburg, Office for Official Publications of the European Communities.

Ernst&Young (2007). Direction Générale de l'Agriculture, OCM Viande Bovine, Évaluation des mesures de marché dans le secteur de la viande bovine. Rapport final. Secteur Public, Ernst & Young Secteur Public: 299.

Eurostat (2008). http://epp.eurostat.ec.europa.eu

Eurostat (2009). http://epp.eurostat.ec.europa.eu

Garnett, T. (2007). Meat and dairy production & consumption: Exploring the livestock sector's contribution to the UK's greenhouse gas emissions and assessing what less greenhouse gas intensive systems of production and consumption might look like. F. C. R. Network. Surrey, UK, Centre for Environmental Strategy, University of Surrey: 169.

Jongeneel, R. and T. Ponsioen (2006). The EU enlargement and the dairy-beef sector: three policy simulations. European Dairy Industry Model FP6 project report. Wageningen, The Netherlands, Department of Social Sciences, Agricultural Economics and Rural Policy Group, Wageningen University: 31.

Monteny, G. J., H. P. Witzke, et al. (2007). Impact assessment of a possible modification of the IPPC Directive. Integrated Measures in Agriculture to reduce Ammonia Emissions. Wageningen, Alterra: 145.

OECD-FAO (2008). Agricultural Outlook 2008-2017 - Highlights, OECD: 73.

Reuters (2007). FACTBOX-Profile of the European Union's livestock sector. http://uk.reuters.com/home.

Steinfeld, H., P. Gerber, et al. (2006). Livestock's long shadow - Environmental issues and options. Rome, FAO.

11.3. References Chapter 3 - Typology of Livestock Production System in Europe

Arrouays, D., Balesdent, J., Germon, J.C., Jayet, P.A., Soussana, J.F., et Stengel, P., (2002). Contribution à la lutte contre l'effet de serre. Stocker du carbone dans les sols agricoles de France? Expertsise scientifique collective. Rapport INRA, 332 p..

Bioteau, T., Burton, C., Guiziou, F., & Martinez, J., CEMAGREF (2009). Qualitative assessment of manure management in main livestock production systems and a review of gaseous emissions factors of manure throughout EU-27 "Studies in support of the European project GGELS"- 100 pp.

Burton, C.H. & Turner, C. (2003). Manure management: Treatment strategies for sustainable agriculture – Eds. Silsoe Research Institute, 2nd edition. ISBN 0 9531282 6 1. pp451.

Chao, A., Chazdon, R.L., Colwell, R.K. & Shen, T.J. (2005). A new statistical approach for assessing similarity of species composition with incidence and abundance data. Ecology Letters, 8: 148–159

INRA, Institut National de la Recherche Agronomique, (2007). Alimentation des bovins, ovins et caprins – Besoins des animaux – valeurs des aliments. Tables Inra 2007, Guide pratique, Quae Eds. ISBN : 978-2-7592-0020-7, pp 307

Micale, F., & Genovese, G. (2005). The MARS Crop Yield Forecasting System. Methodology of the MARS Crop Yield Forecasting System – Vol. 1 – Meteorological data collection, processing and analysis. pp 102. (contact mars-stat@jrc.it or through the web site http://agrifish.jrc.it/marsstat/default.htm)

Nasuelli, P., Palladino, G., Setti, M., Zanasi, C., & Zucchi, G. (1997). CAPRI: Feed module – Requirement functions and restriction factors. Working paper 97-12, http://www.ilr1.uni-bonn.de/agpo/rsrch/capri/wrkpap_e.htm, pp32

Regulation EEC No. 676/1991, (1991). Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources - Official Journal L 375 , 31/12/1991 P. 0001 – 0008 – Annex III, paragraph 2.

Joya, R., (2009). Typologie et caractérisation des systèmes d'élevage bovins laitiers de l'EU 25 en vue d'un quantification des émissions de gaz à effet de serre, Mémoire d'ingénieur, Septembre 2009, 86 pp..

WTO, World Trade Organization, (2003). International trade statistics 2003. pp 232. http://www.wto.org/english/res_e/statis_e/its2003_e/its03_toc_e.htm

11.4. References to Chapter 4 - Methodology for Quantification of greenhouse gas and ammonia emissions from the livestock sector the

Baldi, G., Paruelo, J.M. 2008: Land-Use and Land Cover Dynamics in South American Temperate Grasslands. Ecology and Society, Vol. 13(2).

Bockisch, F.-J., 2000: Bewertung und Verfahren der oekologischen und konventionellen landwirtschaftlichen Produktion im Hinblick auf den Energieeinsatz und bestimmte Schadgasemissionen; Landbauforschung Voelkenrode, special edition 211 (2000), Brunswick.

Boxberger, J., Jauschnegg, H., Amon, B., 1997: Strombedarf in der Landwirtschaft; Verband der Elektrizitaetswerke Oesterreichs (VEOE); 11/97, pp. 80-84, Vienna.

Britz, W., 2004: CAPRI Modelling System Documentation, Final report of the FP5 shared cost project CAP-STRAT "Common Agricultural Policy Strategy for Regions, Agriculture and Trade", QLTR-2000-00394; Universität Bonn.

Cardille, J.A., Foley, J.A. 2003: Agricultural Land-use change in Brazilian Amqazonia between 1980 and 1995: Evidence from integrated satellite and census data. Remote Sensing of Environment, Vol. 87, pp. 551-562, Elesvier.

Carre, F., Hiederer, R., Blujdea, V., Koeble, R. 2009: Guide for the Calculation of Land Carbon Stocks Drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Document prepared as part of the Administrative Arrangement No.: TREN/D1/464-2009-SI2.539303, Ispra.

Dros, J.M., 2004: Managing the Soy boom: Two scenarios of soy production expansion in South America, AIDEnvironment, Amsterdam.

EEA, 2008: Annual European Community greenhouse gas inventory 1990 - 2006 and inventory report 2008; Submission to the UNFCCC secretariat, Copenhagen.

European Commission, 2009: EU Energy and Transport in Figures, Brussels.

FAO, 2005: FAOSTAT Database Output on Pesticides Consumption; URL: http://faostat.fao.org/site/424/default.aspx#ancor; Download date: 17.2.2005, Rome.

Fearnside, P.M. 1996: Amazonian Deforestation and Global Warming: Carbon stocks in vegetation replacing Brazil's Amazon Forest. Forest Ecology and Management, Vol. 80, pp. 21-34, Elesvier.

Fritz, S., McCallum, I., Schill, Ch., Perger, Ch., Grillmayer, R., Achard, F., Kraxner, F., Obersteiner, M. 2009: Geo-Wiki.org: The use of crowdsourcing to improve global land cover. Remote Sensing, Vol.1, pp.345-354.

Garnett, T., 2009: Livestock-related greenhouse gas emissions: impact and options for policy makers, Environmental Science and Policy, Elesvier.

IFA/IFDC/FAO, 2003. Fertilizer use by crop, Fifth edition, Food and Agriculture Organization of the United Nations: Rome.

IPCC, 1997: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, Vol. 3, Paris.

IPCC, 2000: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Japan.

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol.4, Japan.

Jasinski, E., Morton, D., DeFries, R. 2005: Physical Landscape Correlates of the Expansion of Mechanized Agriculture in Mato Grosso, Brazil. Earth Interactions, Vol. 9, Nr. 16.

Klimont Z, Webb J, Daemmgen U., 2005. Livestock husbandry systems in Europe: Evaluation of the 2003 UNECE ammonia expert group questionnaire. In: Emissions from European Agriculture, T. Kuczynski et al. (eds), Wageningen Academic Publishers, Wageningen, Netherlands, pp. 67-92 [2005]

Klimont, Z., 2005, Projections of agricultural emissions of ammonia in the European Union. In: Kuczynski et al. (eds.) Emissions from European Agriculture. Wageningen Academic Publishers, Wageningen, The Netherlands. pp.227-246.

Keiser, H., 1999: Lagerbelueftungstrocknung; RKL 4.3.1.0, Rendsburg-Osterroenfeld.

Kempen, K., Kraenzlein, T., 2008: Energy use in Agriculture: A Modelling Approach to Evaluate Energy Reduction Policies; Paper presented at the 107th EAAE Seminar "Modelling of Agricultural and Rural Development Policies", Sevilla.

Kraenzlein, T., 2008: Economic Monitoring of Fossil Energy Use in EU Agriculture; Unpublished dissertation ETH Nr. 17883, Zuerich.

KTBL, 2004: Betriebsplanung Landwirtschaft 2004/2005: Daten fuer die Betriebsplanung in der Landwirtschaft; KTBL, Darmnstadt.

Lalive d'Epinay, A., 2000: Die Umweltvertraeglichkeit als eine Determinante des architektonischen Entwurfs; dissertation ETH Nr. 13610, Zuerich.

Leip, A., Marchi, G., Koeble, R., Kempen, M., Britz, W., Li, C., 2008. Linking an economic model for European agriculture with a mechanistic model to estimate nitrogen and carbon losses from arable soils in Europe. Biogeosciences 5, 73-94.

McAlpine, C.A., Etter, A., Fearnside, P.M, Seabrook, L, Laurance, W.F., 2009: Increasing world consumption of beef as a driver of regional and global change: A call for policy action based on evidence from Queensland (Australia), Colombia and Brazil. Global Environmental Change, Elesvier.

Moerschner, J., 2000: Stoff- und Energiebilanzen von Ackerbausystemen unterschiedlicher Intensitaet; dissertation.de-Verlag, Goettingen.

Morton, D.C., DeFries, R., Shimabukuro, Y.E., Anderson, L.O, Arai, E., Espirito-Santo, F., Freitas, R., Morisette, J. 2006: Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. www.pnas.org/cgi/doi/10.1073/pnas.0606377103.

Nemecek, T., Heil, A., Huguenin, O., Meier, S., Erzinger, S., Blaser, S., Dux, D., Zimmermann, A., 2003: Life Cycle Inventories of Agricultural Production Systems. Final Report ecoinvent 2000 No. 15, Zuerich.

Nepstad, D.C, Stickler, C.M, Almeida, O.T., 2006: Globalization of the Amazon Soy and Beef Industries: Opportunities for Conservation. Conservation Biology, Vol. 20, Nr.6, 1595-1603, .

NRC 2001: Nutrient Requirements of Dairy Cattle. National Academy Press, Washington D.C.

Orlandini, L., e A. Leip. 2008: A high-resolution dataset of European daily weather from 1990-2000 for applications with ecosystem models. NitroEurope IP Open Science Conference - Reactive Nitrogen and the European Greenhouse Gas Balance. 20.-21. February, 2008, Ghent.

Perez, I., D., 2006: Greenhouse Gases: Inventories, Abatement costs and Markets for Emission Permits in European Agriculture, Frankfurt am Main.

Ramankutty, N., Evan, A. T., Monfreda, C. and Foley, J.A., 2008: Farming the planet: 1.Geographic distribution of global agricultural lands in the year 2000. Global Biogeochemical Cycles, Vol.22, GB 1003, doi: 10.1029/2007/GB$_0$02952.

SALCAo61, 2006: Regular update and enlargement of ecoinvent (2003) agricultural inventories including the impact assessment factors (not published); Agroscope ART Reckenholz, Zuerich.

Sauer, D.B., 1992: Storage of cereal grains and their products; American Association of Cereal Chemists, Inc., St.Paul, Minnesota. sites, Agriculture, Ecosystems & Environment, 121, 121-134.

Sauvant, D., Perez, J.M., Tran, G. 2004 : Tables of Composition and Nutritional Values of Feed Materials. INRA Editions, Paris.

Soussana, J.F., et.al. 2007: Full accounting of the greenhouse gas (CO_2,N_2O,CH_4) budget of nine European grassland sites. Agriculture, Ecosystems and Environment, No 121, pp 121-134.

Soussana, J.F., Tallec, T., Blanfort, V., 2009 : Mitigating the greenhouse gas balance of ruminant production systems through carbon sequestration in grasslands. Forthcoming.

UNECE, 2007: Main transport indicators in the UNECE region 2007, Geneva.

Velthof, G., L., Oudendag, D., A., Oenema, O., 2007: Development and Application of the Integrated Nitrogen Model MITERRA-EUROPE, Alterra report 1663.1, Wageningen.

Velthof, G.,L., Oudendag, D., Witzke, H.,P., Asman, W.,A.,H., Klimont, Z. and Oenema, O. 2009: Integrated Assessment of Nitrogen Losses from Agriculture in EU-27 using MITERRA-EUROPE, Journal of Environmental Quality, No 38/2, pp 402-417.

Vera-Diaz, M.C., Kaufmann, R.K., Nepstad, D.C., Schlesinger, P., 2008: An interdisciplinary model of soybean yield in the Amazon Basin: The climatic, edaphic, and economic determinants, Ecological Economics, Elesvier.

Wood, S., Cowie, A., 2004: A review of greenhouse gas emission factors for fertilizer production. http://ieabioenergy-task38.org/publications/

11.5. References to Chapter 5 – Comparison of EU livestock GHG emissions derived by CAPRI with official GHG inventories

EEA, 2010: Annual European Community greenhouse gas inventory 1990 - 2009 and inventory report 2010; Submission to the UNFCCC secretariat, Copenhagen.

IFA/IFDC/FAO, 2003. Fertilizer use by crop, Fifth edition, Food and Agriculture Organization of the United Nations: Rome.

IPCC, 1997: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, Vol. 3, Paris.

IPCC, 2000: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Japan.

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol.4, Japan.

11.6. References Chapter 7 – Technological abatement measures for livestock rearing emissions

Amon, B., 2001. Emissions of NH_3, N_2O and CH_4 from dairy cows housed in a farmyard manure tyling stall (housing, manure storage, manure spreading). Nutrient Cycling in Agroecosystems, 60:102-113.

Bakken, L., 1994. Energy use and emission of greenhouse gases from grassland agriculture. Grassland-and-society-Proceedings-of-the-15th-General-Meeting-of-the-European-Grassland-Federation,-6-9,-June,-1994. Pg. 361-376.

Berg, W., 2006. Greenhouse gas emissions from covered slurry compared with uncovered during storage. Agriculture, Ecosystems and Environment 112:129-134.

Bicudo, JR, Clanton, CJ, Schmidt, DR, Jacobson, LD, Powers, W, Tengman, CL, 2004. Geotextile covers to reduce odor and gas emissions from swine manure storage ponds. Appl. Eng. Agric. 20, 65-75.

Boehm, N., 2004. Sink potential of Canadian agricultural soils. Climatic Change 65:297-314.

Borjesson,, P., Environmental effects of energy crop cultivation in Sweden-I: Identification and quantification, 1999. Biomass-and-Bioenergy 16(2): 137-154

Chadwick DR, 2005. Emissions of ammonia, nitrous oxide and methane from cattle manure heaps: effect of compaction and covering. Atmospheric Environment 39:787-799.

Clemens J, 2001. Greenhouse gases from animal husbandry: mitigation options. Nurient Cycling in Agroecosystems 60:287-300.

Clemens, J., 2006. Agriculture, Ecosystems and Environment 112:171-177.

Conant, S, 2002. Potential Soil Carbon Sequestration in Overgrazed Grassland Ecosystems. Global Biochemical Cycles 16(4): 1143-1154.

European Environment Agency, 2009. Annual European Community greenhouse gas inventory 1990–2007 and inventory report 2009. Submission to the UNFCCC Secretariat. European Commission, DG Environment and European Environment Agency *Technical report No 04/2009, pg. 634.*

FAL, 1990. Antwort der FAL auf eine grosse Anfrage der Bundestagabgeordeneten Ganseforth und der SPD-Fraktion an die Bundesregierung zur Umsetzung der Empfehlungen der Enquete-Kommission 'Schutz der erde.

FAO, 2006. Livestock’s Long Shadow. ISBN 978-92-5-105571-7, FAO, Rome, pg. 377.

Haeussermann, A.,Hartung, E., Gallmann, E. Jungbluth T., 2006. Influence of season, ventiliation strategy and slurry removall on methane emissions from pighouses, Agriculture, Ecosystems and Environment 112:115-121.

Hansen, M.N., Henriksen, K., Sommer, S.G., 2006. Observations of production and emission of greenhouse gases and ammonia storage of solids separated from pig slurry: Effects of covering. Atmospheric Environment 40:4172-4182.

Klimont, Z., Brink, C., 2004: Modelling of Emissions of Air Pollutants and Greenhouse Gases from Agricultural Sources in Europe. Research Report, Laxenburg.

Kuikman, P.J., D.A. Oudendag, A. Smit, K.W. van der Hoek (2004). ROB maatregelen in de landbouw en vermindering van emissies van broeikasgassen. Wageningen, Alterra, pp142. Alterra report 994. In: Proceedings of the 3rd International Methane and Nitrous Oxide Mitigation Conference. Beijing; pp415-422, 2003

Mol, R.M. de, M.A. Hilhorst (2003). Methaan-, lachgas- en ammoniakemissie bij productie, opslag en transport van mest. Wageningen, IMAG, pp252. Reportnr 2003-03

Oenema, O., Velthof, G.L., P.J. Kuikman, 2001. Technical and policy aspects of strategies to decrease greenhouse gas emissions from agriculture. Nutrient Cycling in Agroecosystems 60:301-315.

Oenema, O., Wrage, N., Velthof, G.L, Groenigen, J.W., Dolfin, J., Kuikman, P.J., 2005. Trends in Global Nitrous Oxide Emissions from Animal Production Systems. *Nutrient Cycling Agroecosys.* 72(1): 51-65.

Pattey E, Trzcinski MK, Desjardins RL, 2005. Quantifying the reduction of greenhouse gas emissions as a result of composting dairy and beef cattle manure. Nutrient cycling in agroecosystems 72(2): 173-187.

Petersen, S.O. and Miller, D.N., 2006. Greenhouse gas mitigation by covers on livestock slurry tanks and lagoons? Journal of the Science of Food and Agriculture 86, 1407-1411.

Petersen, SO, Amon, B, Gattinger, A., 2005. Methane oxidation in slurry storage surface crusts. J. Environ. Qual. 34, 1421-1426.

PICCMAT, 2010. http://www.climatechangeintelligence.baastel.be/piccmat/index.php.

Smith P, Goulding KW, Smith KA, Powlson DS, Smith JU, Falloon P, Coleman K, 2001 Enhancing the carbon sink in European agricultural soils: including trace gas fluxes in estimates of carbon mitigation potential. Nutrient cycling in Agroecosystems 60: 237-252.

Smith P, Powlson DS, Smith JU, Falloon P, Coleman K, 2000. Meeting Europe's climate change commitments: quantitative estimates of the potential for carbon mitigation by agriculture. Global Change Biology 6:525-539.

Sommer, S.G., Møller, H.B. & Petersen, S.O., 2001. Reduktion af drivhusgasemission fra gylle og organisk affald ved Biogasbehandling. DJF rapport - Husdyrbrug, 31, 53 pp.

Sommer, S.G., Møller, H.B., 2000. Emission of greenhouse gases during composting - effect of straw content. Journal of Agricultural Science 134:327-335.

Sommer, SO, Petersen, SO, Møller, HB. 2004. Algorithms for calculating methane and nitrous oxide emissions from manure management. Nutr. Cycl. Agroecosyst. 69, 143-154.

Soussana, J.F., 2001. Sources et puits de gaz à effet de serre (CO_2, CH_4, N_2O) en prairie pâturée et stratégies de réduction. Rapport final, Apr 2001 INRA

Soussana, J.F., V. Allard, K. Pilegaard, P. Ambus, C. Amman, C. Campbell, E. Ceschia, J. Clifton-Brown, S. Czobel, R. Domingues, C. Flechard, J. Fuhrer, A. Hensen, L. Horvath, M. Jones, G. Kasper, C. Martin, Z. Nagy, A. Neftel, A. Raschi, S. Baronti, R.M. Rees, U. Skiba, P. Stefani, G. Manca, M. Sutton, Z. Tuba, R. Valentini, 2007. Full accounting of the greenhouse gas (CO_2, N_2O, CH_4) budget of nine European grassland sites. *Agr. Ecosys. Env.* 121 (2007) 121–134.

Tubiello, F.N., and Fischer. G., 2007. Reducing climate change impacts on agriculture: Global and regional effects of mitigation, 1990-2080. *Tech. Forecasting and Soc. Ch 74:1030-1056.*

USDA, 2010. EU-27 Grain and Feed Annual 2010, Special Publication, GAIN Report Apr 30 2010.

van den Pol-van Dasselaar, A. 2002. The effect of ploughing of grasslands on nitrous oxide emission, Grassland Science in Europe 3:742-743.

Veen, W.A.G. van, 2000. Veevoermaatregelen ter vermindering van methaanproductie door herkauwers. Lelystad, Schothorst.

Vellinga, T.V., P.J. Kuikman, A. van den Pol-van Dasselaar, 2000. Beperking van lachgasemissie bij het scheuren van grasland: een systeemanalyse. Wageningen, Alterra, pp 59. Alterra-report 114.5 Alterra-rapport 114.5, 2000

Vellinga, Th. V., A. van den Pol-van Dasselaar, P.J. Kuikman, 2004. The impact of grassland ploughing on CO_2 and N_2O emissions in the Netherlands. Nutrient Cycling in Agroecosystems 70: 33-45.

Velthof, G.L., J. Dolfing, G.J. Kasper, J.W. van Groeningen, W.J.M. de Groot, A. van den Pol-Dasselaar & P.J. Kuikman, 2003. Beperking van lachgasemissie uit bemeste landbouwgronden. Eindrapport Reductie Plan Overige Broiekasgassen Landbouw Cluster 1. Wageningen, Alterra, pp 58. Alterra report 560.2

Velthof, G.L., M.H. de Haan, R.L.M. Schils, G.J. Monteny, A.van den Pol-van Dasselaar, P.J. Kuikman, 2000. Beperking van lachgasemissie uit bemeste landbouwgronden; een systeemanalyse. Wageningen, Alterra, pp 69. Alterra report 114.2.

Velthof, G., L., Oudendag, D., A., Oenema, O., 2007: Development and Application of the Integrated Nitrogen Model MITERRA-EUROPE, Alterra report 1663.1, Wageningen.

Weske, A., 2006. Mitigation of greenhouse gas emission in European conventional and organic dairy farming Agriculture, Ecosystems and Environment 112:221-232.

Wulf, S., et al., 2002. J. Env. Quality 31:1795-1801.

11.7. References to Chapter 8 - Prospective overview of EU livestock emission

Böhringer, C. (2000). Cooling down hot air: a global CGE analysis of Post-Kyoto carbon abatement strategies, Energy Policy, 28, pp.779–789, doi: 10.1016/S0301-4215(00)00060-4, Elsevier

Breen J.P. (2008). Simulating a market for tradable greenhouse gas emissions permits amongst Irish farmers, 82nd annual conference of the Agricultural Economics Society, Royal Agricultural College, 31st-2nd April.

Britz W, Witzke P (2008) CAPRI model documentation 2008: Version 1 http://www.capri-model.org/docs/capri_documentation.pdf

Council of the European Union (2003). Council Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC, Official Journal of the European Communities, L275.

Eckermann F., Hunt A., Stronzik M., Taylor T. (2003). The role of transaction costs and risk premia in the determination of climate change policy responses, Diskussionspapier No. 03-59, Zentrum für Europäische Wirtschaftsforschung, pp. 28.

Commission of the European Communities (2007). Rural Development in the European Union – Statistical and Economic Information, Report 2007, Directorate Generale for Agriculture and Rural Development, Brussels

FAO (2006) "Livestock long shadow: environmental issues and options", Food and Agriculture Organisation, Rome.

Gielen D., Fujino J., Hashimoto S. and Moriguchi Y. (2003). Modeling of global biomass policies, Biomass and Bioenergy 25, pp.177-195, Elsevier

Irish Times (2009) 'Cow tax' may be introduced to reduce emissions, Monday, March 9th 2009

Jorgenson D., Goettle R., Sing Ho M. and Wilcoxen P. (2009) Cap and trade climate policy and U.S. economic adjustments, Journal of Policy Modeling, 31, pp.362-381, doi: 10.1016/j.jpolmod.2008.09.006, Elsevier

Kerr S. and Sweet A. (2008). Inclusion of agriculture and forestry in a domestic emissions trading scheme: New Zealand's experience to date, Motu Economic and Public Policy Research, Working Paper 08-04, Wellington, New Zealand.

Lal R. (2004). Agricultural activities and the global carbon cycle, Nutrient Cycling in Agroecosystems, 70, pp. 103-116, Kluwer Academic Publishers

Lenno$_x$ J.A., Andrew R. and Forgie V. (2008). Price effects of an emission trading scheme in New Zealand. Paper prepared for presentation at the 107th EAAE Seminar 'Modelling of Agricultural and Rural Development Policies', Seville, Spain, January 29th-Febrruary 1st

Moran D., McLeod M., Wall E., Eory V., McVittie A., Barnes A., Rees B., Smith P. and Moxey A. (2009) Marginal abatement cost curves for UK agriculture, forestry, land-use and land-use change sector out to 2022, Paper presented at the Agricultural Economics Society 83rd Annual Conference, Dublin, 31 March – 1 April 2009

Nowicki, P., V. Goba, A. Knierim, H. van Meijl, M. Banse, B. Delbaere, J. Helming, P. Hunke, K. Jansson, T. (2009) Scenar 2020-II – Update of Analysis of Prospects in the Scenar 2020 Study – Contract No. 30–CE-0200286/00-21. European Commission, Directorate-General Agriculture and Rural Development, Brussels.

Phatak H., Jain N., Bhatia A., Mohanty S. and Gupta N. (2009) Global warming mitigation potential of biogas plants in India, Environmental Monitoring Assessment, 157, 407-418, doi: 10.1007/s10661-008-0545-6, Springer.

Radov D, Klevnas P and Skurray J (2007). Market mechanisms for reducing GHG emissions from agriculture, forestry and land management, London: NERA Economic Consulting.

Reilly J.M., Asadoorian. M.O (2007) Mitigation of greenhouse gas emissions from land use: creating incentives within greenhouse gas emission trading systems, Climatic Change, 1-2, 173 197, doi: 10.1007/s10584-006-9151-1, Springer.

Saddler H., King H. (2008) Agriculture and emissions trading. The impossible dream?, The Australia Institute, Discussion Paper 102.

Truong T.P, Kemfert C and Burniaux J.M (2007) GTAP-E: an energy-environmental version of the GTAP model with emission trading, Deutsches Institut für Wirtschaftsforschung, discussion papers 668, Berlin.

11.8. References Chapter 9.1 - Overview of the impact of the livestock sector on EU biodiversity

ADAS 2007: The Environmental Impact of Livestock Production. Report for Defra FFG, 102 pp.

Andersen E. (ed.) 2003. Developing a high nature value farmland area indicator. Internal report. EEA, Copenhagen.

Baldock D., Beaufoy G., Bennett G., Clark J., 1993. Nature conservation and new directions in the common agricultural policy. IEEP London.

Baldock, D., Beaufoy, G., Clark, J., 1995. The nature of farming. Low intensity farming systems in nine European countries. Report IEEP/WWF/JNRC. London/Gland/Peterborough.

Benton T.G., Vickery J.A., Wilson J.D., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends in Ecology and Evolution, 18, 4, 182-188.

Bignal E.M., McCracken D.I., 1996. Low-intensity farming systems in the conservation of the countryside. Journal of Applied Ecology, 33, 413-424.

Bobbink R., Hornung M., Roelofs J.G.M., 1998. The effects of air-borne nitrogen pollutants on species diversity in natural and semi-natural European vegetation. Journal of Ecology, 86, 717-738.

Collinge S. K., Prudic K. L. and Oliver J. C. (2003). Effects of local habitat characteristics and landscape context on grassland butterfly diversity. Cons. Biol., 17: 178-187.

Delbaere B., Nieto Seradilla A., 2004. Environmental risks from agriculture in Europe: Locating environmental risk zones in Europe using afro-environmental indicators. Tilburg, ECNC – European Centre for Nature Conservation, 184 pp.

Duelli P., Obrist M. K. and Schmatz D. R. (1999). Biodiversity evaluation in agricultural landscapes: above-ground insects. Agric. Ecosys. Environm. 74: 33-64.

Duncan A., 2005. Farm animals and biodiversity. Animal Science, 81, 187-188.

EEA, 2004. High nature value farmland: Characteristics, trends and policy challenges. European Environment Agency, Report No 1/2004. Luxembourg: Office for Official Publications of the European Communities.

EEA, 2009. Progress towards the European 2010 biodiversity target. EEA Report No 4/2009. European Environment Agency, Copenhagen, Denmark.

EEA, 2009. Assessing biodiversity in Europe – the 2010 report. EEA Report No 5/2010. European Environment Agency, Copenhagen, Denmark.

EC (1999), Communication from the Commission to the Council; the European Parliament; The Economic and Social Committee and the Committee of the Regions Directions towards Sustainable Agriculture. Commission of the European Communities. Brussels, 27.01.1999 Com (1999), 22 final, available at: http://ec.europa.eu/agriculture/envir/9922/9922_en.pdf, .

Eickhout B., Bouwman A.F., van Zeijts H., 2006. The role of nitrogen in world food production and environmental sustainability. Agric, Ecosys & Envir, 116, 4-14.

Eppink F.V., Rietveld P., van den Bergh J.C.J.M., Vermaat J.E., Wassen M.J., Hilferink M., Internalising the costs of fragmentation and nutrient deposition in spatial planning: Extending a decision support tool for the Netherlands. Land Use Policy, 25, 563-578.

Erisman J.W., Bleeker A., Hensen A., Vermeulen A., 2008. Agricultural air quality in Europe and the future perspectives. Atmospheric Environment, 42, 3209–3217.

Finck P., Riecken U., Schröder E., 2002 . Pasture landscapes and nature conservation ~ new strategies for the preservation of open landscapes in Europe. Springer-Verlag.

Firbank L.G., Petit S., Smart S., Blain A., Fuller R.J., 2008. Assessing the impacts of agricultural intensification on biodiversity: a British perspective. Phil. Trans. R. Soc. B, 363, 777-787.

Fraser I., Stevens C., 2008. Nitrogen deposition and loss of biological diversity: Agricultural land retirement as a policy response. Land Use Policy, 25, 455–463.

Gac A., Béline F., Bioteau T., Maguet K., 2007. A French inventory of gaseous emissions (CH_4, N_2O, NH_3) from livestock manure management using a mass-flow approach. Livestock Science, 112, 252–260.

Hampicke, U., 2006. Efficient conservation in Europe's agricultural countryside—rationale, methods and policy reorientation. Outlook Agric. 35 (2).

Herzog F., Dreier S., Hofer G., Marfurt C., Schüpbach B., Spiess M., Walter T., 2005. Effect of ecological compensation areas on floristic and breeding bird diversity in Swiss agricultural landscapes. Agric, Ecosys &Environm, 108, 189-204.

Hester A.J., Bergman M., Iason G.R., Moen J., 2005. Impact of large herbivores on plant community structure and dynamics. In: Large herbivore ecology and ecosystem dynamics (ed. K. Danell, R. Bergstrom, P. Duncan and J. Pastor), Cambridge University Press.

Hinsley S. A. and Bellamy P. E. (2000). The influence of hedge structure, management and landscape context on the value of hedgerows to birds: A review. Journ; of Environm. Management, 60: 33-49.

Isselstein J., Jeangros B., Pavlu V., 2005. Agronomic aspects of biodiversity targeted management of temperate grasslands in Europe – A review. Agron. Res., 3, 139-151.

Keenleyside C., Baldock D., 2007. Background paper. In: The relationships between the CAP and biodiversity. Outcome of an international seminar in Warsaw, Poland 7-8 December 2006. DLG Government Service for Land and Water Management, Utrecht, The Netherlands, 29-55.

Krupa S.V., 2003. Effects of atmospheric ammonia (NH_3) on terrestrial vegetation: a review. Environmental Pollution, 124, 179–221.

Leip A., Achermann B., Billen G., Bleeker A., Bouwman L., de Vries W., Dragosits U., Döring U., Fernall D., Geupel M., Johnes P., Le Gall A. C., Monni S., Nevečeřal R., Orlandini L., Prud'homme M., Reuter H., Simpson D., Seufert G., Spranger T., Sutton M., van Aardenne J., Voss M. and Winiwarter W. (2011). Integrating nitrogen fluxes at the European scale. In: European Nitrogen Assessment (Chapter 16). Billen G., Bleeker A., Erisman J. W., Grennfelt P., Grizzetti B., Howard C., Sutton M., and van Grinsven H. (Editors). Cambridge, UK: Cambridge University Press. p. xx-xxx.

Lord E.I., Anthony S.G., Goodlass G., 2002. Agricultural nitrogen balance and water quality in the UK. Soil Use and Management, 18, 363-369.

Luoto M., Rekolainen S., Aakkula J., Pykälä J., 2003. Loss of Plant Species Richness and Habitat Connectivity in Grasslands Associated with Agricultural Change in Finland. Ambio, 32, 447-452.

Marriott C.A., Carrère P., 1998. Structure and dynamics of grazed vegetation. Ann. Zootech., 47, 359-369.

Marshall E.J.P., Moonen A.C., 2002. Field margins in northern Europe: their functions and interactions with agriculture. Agric., Ecos. & Envir., 89, 5-21.

Milne J.A., 2005. Societal expectations of livestock farming in relation to environmental effects in Europe. Livestock Production Science, 96, 3-9.

Moss B., 2008. Water pollution by agriculture. Phil. Trans. R. Soc. B, 363, 659–666.

Naylor R., Steinfeld H., Falcon W., Galloway J., Smil V., Bradford E., Alder J., Mooney H., 2005. Loosing the links between livestock and land. Science, 310, 1621-1622.

Nösberger J., Messerli M., Carlen C., 1998. Biodiversity in grassland. Ann. Zootechn., 47, 383-393.

Opdam P., Wascher D., 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biological Conservation, 117, 285–297.

Oenema O., Oudendag D., Velthof G.L., 2007. Nutrient losses from manure management in the European Union. Livestock Science, 112, 261-272.

Ostermann, O.P., 1998. The need for management of nature conservation sites under Natura 2000, Journal of Applied Ecology 35: 968-973.

Ouin A., Burel F., 2002.Influence of herbaceous elements on butterfly diversity in hedgerow agricultural landscapes. Agric., Ecos. & Envir, 93, 45-53.

Papanastasis V.P., Chourvadas D., 2005. Application of the state-and-transition approach to conservation management of a grazed Mediterranean landscape in Greece. Israel Journal of Plant Sciences, 53, 191-202.

Paracchini M.L., Petersen J-E., Hoogeven Y., Bamps C., Burfield I., van Swaay C., 2008. High Nature Value Farmland in Europe - An Estimate of the Distribution Patterns on the Basis of Land

Cover and Biodiversity Data. JRC Report EUR 23480 EN. Luxembourg: Office for Official Publications of the European Communities

Petit S., Firbank L., Wyatt B., Howard D., 2001. MIRABEL: Models for Integrated Review and Assessment of Biodiversity in European Landscapes. Ambio, 30 81-88.

Petit S., Elbersen B., 2006. Assessing the Risk of Impact of Farming Intensification on Calcareous Grasslands in Europe: A Quantitative Implementation of the MIRABEL Framework. Ambio, 35, 297-303,

Plieninger T., Höchtl F., Spek T., 2006. Traditional land-use and nature conservation in European rural landscapes. Environmental Science & Policy, 9, 317-321.

Pöyry J., Lindgren S., Salminen J., Kuussaari M., 2005. Responses of butterfly and moth species to restored cattle grazing in semi-natural grasslands. Biological Conservation, 122, 465–478.

Rook A.J., Dumont B., Isselstein J., Osoro K., WallisDe Vries M.F., Parente G., Mills J., 2004. Matching type of livestock to desired biodiversity outcomes in pastures – a review. Biological Conservation, 119, 137-150.

Steinfeld H., Mooney H.A., Schneider F., Neville L.E. (eds.), 2010. Livestock in a changing landscape. Vol. 1: Drivers, consequences and responses. Inland Press.

Stevens C.J., Dise N.B., Mountford O., Gowing D.J., 2004. Impact of nitrogen deposition on the species richness of grasslands. Science, 303, 1876-1879.

Tamminga S., 2003. Pollution due to nutrient losses and its control in European animal production. Livestock Production Science, 84, 101-111.

Tilman D., et al., 2001. Forecasting agriculturally driven global environmental change. Science, 292, 281-284.

Tucker G.M., 1997. Priorities for bird conservation in Europe: the importance of the farmed landscape. In: Pain D. and Pienkowski M.W. (eds.) Farming and birds in Europe: the common agricultural policy and its implications for bird conservation, pp. 79-116. Academic Press, London.

van Swaay, C.A.M. & M.S. Warren (eds.) (2003). Prime Butterfly areas in Europe: Priority sites for conservation. National Reference Centre, Ministry of Agriculture, Nature and Food Quality, The Netherlands.

Vos W., Meekes H., 1999. Trends in European cultural landscape development: perspectives for a sustainable future. Landscape Urban Planning, 46, 3-14.

Wamelink G.W.W., de Jong J.J., Van Dobben H.F., Van Wijk M.N., 2005. Additional costs of nature management caused by deposition. Ecological Economics 52, 437– 451.

Webb J., Menzi H., Pain B.F., Misselbrook T.H., Dämmgen U., Hendriks H., Döhler H., 2005. Managing ammonia emissions from livestock production in Europe. Environmental Pollution, 135, 399–406.

Zarovali M.P., Yiakoulaki M.D., Papanastasis V.P., 2007. Effects of shrub encroachment on herbage production and nutritive value in semi-arid Mediterranean grasslands. Grass and Forage Science, 62, 355-363.

11.9. References Chapter 9.2 - Estimation of emissions of imported animal products

ABARE & MAF, 2006. Agricultural Economies of Australia and New Zealand: Past, Present, Future. ABARE, Canberra. http://www.abareconomics.com/interactive/ausNZ_ag/pdf/ausNZ_nz_n.pdf

Barber, A. and Lucock, D. 2006. Total Energy Indicators: Benchmarking Organic, Integrated and Conventional Sheep and Beef Farms. ARGOS research report number 06/07. http://www.argos.org.nz/pdf_files/Research_Report_0607_SB_Energy_Indicators.pdf

Bernoux, M., Volkoff, B., Carvalho, M. and Cerri, C. 2003. CO_2 emissions from liming of agricultural soils in Brazil. Global Biogeochemical Cycles 17(2) doi:10.1029/2001GB$_0$01848.

Carvalho, C.F.C. 2006. Country Pasture/Forage Resource Profiles. Brazil. Originally prepared in 2002, revised in 2006. http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Brazil/Brazil.htm

Cederberg, C., Neovius, K., Meyer, D. and Flysjo, A. (unpublished). Top-down life-cycle accounting of greenhouse gas emissions and use of land and energy of Brazilian beef imported to Europe. SIK-report, in preparation. Confidential draft 2009 02 06.

Chapagain, A. and Hoekstra, A. 2004. Water footprints of nations. Volume 2: Appendices. UNESCO-IHE. Institute for Water Education.

Clement, C., 1997. Environmental impacts of, and biological and socio-economic limitations on new crop development in Brazilian Amazonia. In: Smartt, J. & N. Haq (eds) 1997. Domestication, Production and Utilization of New Crops. International Centre for Underutilised Crops, Southampton, UK. pp. 134-146.

EDGAR. Emissions Database for Global Atmospheric Research. Joint Research Centre of the European Commission. http://edgar.jrc.ec.europa.eu/

FAOSTAT, 2008. Statistics of Food and Agriculture Organization of the United Nations. http://faostat.fao.org/

FAO, 2005. Livestock sector brief. Brazil. Food and Agriculture Organization of the United Nations. Livestock Information, Sector Analysis and Policy Branch.

FAO, 2006. Livestock's long shadow. Environmental issues and options. FAO.

FAO/IFA – data on N fertilizer use per crop.

IFA, 2007. IFADATA statistics. Production, imports, exports and consumption data for nitrogen, phosphate and potash fertilizers. International Fertilizer Industry Association. CD-ROM.

IPCC, 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Houghton, J., Ding, Y., Griggs, D., Noguer, M., van der Linden, P., Dai, X., Maskell, K. and Johnson, C. (eds). Cambridge, UK and New York, Cambridge University Press. 881 pp.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Eggleston, S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds). IGES, Japan.

McAlpine, C., Etter, A., Fearnside, P., Seabrook, L. and Laurance, W. in press. Increasing world consumption of beef as a driver of regional and global change: a call for policy action based on evidence from Queensland (Australia), Colombia and Brazil. Global Environmental Change (2008).

Ministry for the Environment, 2008. New Zealand's Greenhouse Gas Inventory 1990–2006. Fulfilling reporting requirements under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Ministry of the Environment, Wellington, New Zealand. http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/4303.php

Ministry of Science and Technology, 2004. Brazil'z Initial National Communication to the United Nations Framework Convention on Climate Change. Ministry of Science and Technology, Brazil.

Sainz, R. 2003. Framework for calculating fossil fuel use in livestock systems. Livestock, Environment and Development initiative report. (Available at ftp://ftp.fao.org/docrep/nonfao/LEAD/X6100E/X6100E00.PDF).

Saggar, S., Hedley, C., Giltrap, D., Lambie, S. 2007. Measured and modelled estimates of nitrous oxide emission and methane consumption from a sheep-grazed pasture. *Agriculture, Ecosystems and Environment* 122 (2007) 357–365.

Saunders, C., Barber, A. and Taylor, G. 2006. Food Miles – Comparative Energy/Emissions Performance of New Zealand's Agriculture Industry. Lincoln University. Research Report No. 285. http://www.lincoln.ac.nz/story_images/2328_RR285_s13389.pdf

Silva, F., 2007. Brazil Livestock and products. Semi-Annual Livestock Report 2007. USDA Foreign Agricultural Service. GAIN report number BR 7608.

Statistics New Zealand, 2008. 2007 Agricultural Production Census – Agriculture. http://www.stats.govt.nz/economy/primary-production/agriculture.htm

Wassenaar, T., Gerber, P., Verburg, P., Rosales, M., Ibrahim,M., Steinfeld, H. 2007. Projecting land use changes in the Neotropics: The geography of pasture expansion into forest. Global Environmental Change 17, 86–104.

Wood & Cowie, 2004. A review of Greenhouse Gas Emission Factors for Fertiliser Production. For IEA Bioenergy Task 38.

12. 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

13. ANNEXES