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Greenhouse gas emission profiles of European livestock sectors

J.P. Lesschen[a,*], M. van den Berg[b], H.J. Westhoek[b], H.P. Witzke[c], O. Oenema[a]

[a] Alterra, Wageningen University and Research Centre, P.O. Box 47, 6700 AA, Wageningen, The Netherlands
[b] PBL – Netherlands Environmental Assessment Agency, P.O. Box 303, 3720 AH, Bilthoven, The Netherlands
[c] Eurocare Bonn and Institute of Agricultural Policy, Market Research and Economic Sociology, Bonn University, Nussallee 2, 53115 Bonn, Germany

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ABSTRACT

There are increasing concerns about the ecological footprint of global animal production. Expanding livestock sectors worldwide contribute to expansion of agricultural land and associated deforestation, emissions of greenhouse gases (GHG), eutrophication of surface waters and nutrient imbalances. Farm based studies indicate that there are large differences among farms in animal productivity and environmental performance. Here, we report on regional variations in dairy, beef, pork, poultry and egg production, and related GHG emissions in the 27 Member States of the European Union (EU-27), based on 2003–2005 data. Analyses were made with the MITERRA-Europe model which calculates annual nutrient flows and GHG emissions from agriculture in the EU-27. Main input data were derived from CAPRI (*i.e.*, crop areas, livestock distribution, feed inputs), GAINS (*i.e.*, animal numbers, excretion factors, NH_3 emission factors), FAO statistics (*i.e.*, crop yields, fertilizer consumption, animal production) and IPCC (*i.e.*, CH_4, N_2O, CO_2 emission factors). Sources of GHG emissions included were enteric fermentation, manure management, direct and indirect N_2O soil emissions, cultivation of organic soils, liming, fossil fuel use and fertilizer production. The dairy sector had the highest GHG emission in the EU-27, with annual emission of 195 Tg CO_2-eq, followed by the beef sector with 192 Tg CO_2-eq. Enteric fermentation was the main source of GHG emissions in the European livestock sector (36%) followed by N_2O soil emissions (28%). On a per kg product basis, beef had by far the highest GHG emission with 22.6 kg CO_2-eq/kg, milk had an emission of 1.3 kg CO_2-eq/kg, pork 3.5 kg CO_2-eq/kg, poultry 1.6 kg CO_2-eq/kg, and eggs 1.7 kg CO_2-eq/kg. However large variations in GHG emissions per unit product exist among EU countries, which are due to differences in animal production systems, feed types and nutrient use efficiencies. There are, however, substantial uncertainties in the base data and applied methodology such as assumptions surrounding allocation of feeds to livestock species. Our results provide insight into differences in GHG sources and emissions among animal production sectors for the various regions of Europe.

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Abbreviations: BAT, best available techniques; CAPRI, Common Agricultural Policy Regionalised Impact; EF, emission factors; EU, European Union; GAINS, Greenhouse Gas and Air Pollution Interactions and Synergies; GHG, greenhouse gas; LCA, life cycle assessment; LU, livestock units; NUTS-2, Nomenclature of Territorial Units for Statistics.

* Corresponding author. Tel.: +31 317 484687; fax: +31 317 419000.
E-mail address: JanPeter.Lesschen@wur.nl (J.P. Lesschen).

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1. Introduction

There are increasing concerns about the ecological footprint of animal production (Delgado et al., 1999; Smil, 2002; Steinfeld et al., 2006, 2010; Galloway et al., 2007). Livestock production systems have been linked to expansion of agricultural land and associated deforestation, emissions of the greenhouse gases (GHG; Steinfeld et al., 2006), eutrophication of surface waters (Seitzinger et al., 2005; Boyer et al., 2006) and nutrient imbalances, with large surpluses in Europe and China and soil nutrient depletion in Africa and South America (Smaling et al., 2008; Menzi et al., 2010). Landless animal production systems import most animal feeds from elsewhere, while manure is often not transported back thereby impeding nutrient recycling (Naylor et al., 2005). However, farmers, animal feed companies and meat processing industries invest in large specialized animal production systems because of their high productivity/unit of labour, capital and land. These systems benefit from economies of scale, specialization and intensification (Roberts, 2008).

Cattle (*i.e.,* dairy, beef), pigs and poultry are the dominant world livestock, but Europe maintains one of the highest livestock densities in the world. In 2008, the 27 member states of the European Union (EU-27) produced; 26%, 13%, 22%, 12% and 11% of the world's milk, beef, pork, poultry and eggs, respectively (FAO, 2008). Following considerable growth in the 1960s and 1970s, cattle numbers in Europe have been decreasing since 1980s. The number of pigs in the EU has stabilized since the mid 1980s, whereas the number of poultry is increasing.

Reduced animal production in Western Europe is related to market developments as well as to changes in agricultural and environmental policies. For example, the milk quota system introduced in 1984, increasing milk yields/cow, and collapse of centrally planned economies in Central Europe during the early 1990s all contributed to the decrease in cattle numbers. The Nitrates Directive (91/676/EEC) limits application of animal manure N in 'nitrate vulnerable zones' to a maximum of 170 kg/ha/yr, corresponding to ~1.7 livestock units (LU)/ha (1 LU is the relative weight of a mature dairy cow, see Fig. 2). Large pig and poultry farms require a permit (*i.e.,* 'license to produce') and must adopt best available techniques (BAT) prescribed by IPPC Directive 2008/1/EC.

According to Steinfeld et al. (2006), about 18% of global GHG emissions are caused by livestock production in some way. Ruminants produce CH_4 during enteric fermentation of feed and CH_4 and N_2O are released from stored manure. Following their application to agricultural land, manure and N fertilizers increase emissions of N_2O from soils. CO_2 and N_2O are released during production of synthetic N based fertilizers. Additionally, deforestation and conversion of grassland into agricultural land release considerable quantities of CO_2 and N_2O into the atmosphere (FAO, 2010).

Farm based studies indicate that there are large differences among farms in animal productivity and environmental impacts (Aarts et al., 1992; Ondersteijn et al., 2002; Thomassen et al., 2008; Powell et al., 2010). These differences are often related to management skills of farmers, technologies applied and/or environmental conditions. Results of these farm scale studies provide insights to policy makers for possible incentives to further improve animal productivity and reduce emissions of specific farms. While comparisons at a regional or country level are not available, results of such a study would provide information on differences in emissions among regions and could aid in identification of management practices that lower emissions.

Our objective was to assess regional differences in GHG emissions associated with production of dairy, beef, pork, poultry and eggs in the EU-27. For the assessment we used the MITERRA-Europe model (Velthof et al., 2009). We first quantified the area of agricultural land needed for animal feed production, then assessed GHG emissions from the different sources related to livestock production. Based on these data, average GHG emissions per livestock sector and animal product were determined. Finally, we discuss the results in the context of options to reduce livestock based GHG emissions in Europe.

2. Methodology

2.1. Conceptual model

Fig. 1 is the conceptual model used, including main input data, their respective sources and data flows. For calculations, the MITERRA-Europe was used, which is described below. We restricted the assessment to dairy, beef, pork and poultry (both eggs and meat) sectors, which are the main livestock sectors in Europe. Emissions related to production of animal feed and livestock were included, but emissions from transport and processing of animal feed and livestock products were not included. Neither did we include emissions related to land use change. Although emissions due to land use change can be substantial (FAO, 2010), their quantification and allocation to commodities is conceptually and methodologically difficult (Dalgaard et al., 2008 and Nguyen et al., 2010a).

With respect to the definition of boundaries for sectors with multiple primary products (*i.e.,* milk and meat, eggs and meat) we used the option that was most straightforward and easiest to implement in respect to available data as described below. GHG emissions, both direct (*i.e.,* from enteric fermentation, manure management) and indirect (*i.e.,* from soil emissions, fuel use and fertilizer production), from mature dairy cows were attributed to the dairy cow sector, whereas GHG emissions related to calves and heifers were attributed to the beef sector. All meat arising from slaughter of dairy cows was attributed to the beef sector. For the poultry sector, GHG emissions from laying hens were attributed to eggs, whereas GHG emissions from broilers and other poultry were attributed to poultry. No correction was made for meat from laying hens.

Results for the sheep and goat sector were not included. Although data were available and we calculated total GHG emissions of this sector, results among countries had a high degree of uncertainty due to a scarcity of population estimates and/or

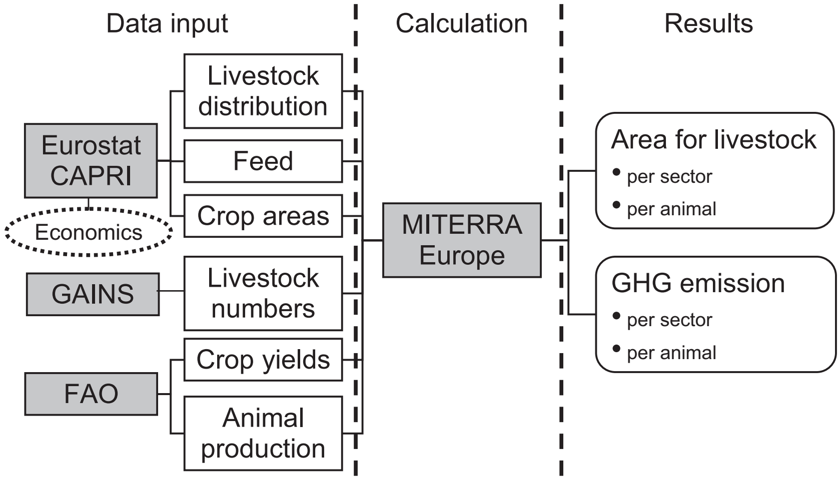

Fig. 1. Conceptual model and data flows.

a lack of distinction between the milk and meat production sectors. In addition, it appeared that statistics on production and trade within this sector were less reliable compared to other livestock sectors, probably due to the more extensive character of this sector.

2.2. MITERRA-Europe

MITERRA-Europe is an environmental assessment model which calculates emissions of N as N_2O, NH_3, NO_x and NO_3, and greenhouse gases as CO_2, CH_4 and N_2O on a deterministic and annual basis using emission and leaching fractions. The MITERRA-Europe model was developed to assess effects and interactions of policies and measures in agriculture on N losses on a NUTS-2 (Nomenclature of Territorial Units for Statistics) level in the EU-27 (Velthof et al., 2009). MITERRA-Europe is partly based on the models CAPRI (Common Agricultural Policy Regionalised Impact), and GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies), supplemented with an N leaching module, a soil C module and a module for mitigation. Input data consists of activity data (*e.g.,* livestock numbers, crop areas, animal production from Eurostat and FAO), spatial environmental data (*e.g.,* soil and climate data) and emission factors from IPCC and GAINS. The model includes measures to mitigate GHG and NH_3 emissions and NO_3 leaching.

CAPRI (www.capri-model.org) is an agricultural sector model at a NUTS-2 level in EU-27, with a global market model for agricultural products. The model considers agricultural supply from 35 crops and 19 animal categories. Feed, forage and fertilizer inputs are modelled in detail. The CAPRI database relies on Eurostat statistics, supplemented with output from a data consolidation routine that accounts for missing or internally inconsistent data. Model outcomes include cropped areas, numbers of animals, environmental indicators and the economic consequences of environmental and economic policies. A detailed description of the CAPRI modelling system is in Britz and Witzke (2008). The GAINS model (www.gains.iiasa.ac.at/gains/) estimates current and future gaseous N and C emissions from agriculture and other sectors in Europe. It incorporates databases on economic activities as well as forecasts of agricultural activities and livestock numbers. Emission factors and removal efficiencies used in GAINS are derived from various studies and national experts (Klimont and Brink, 2004).

For N_2O and CH_4, IPCC (2006) emission factors were used and emission factors from GAINS were used for NH_3 (Klimont and Brink, 2004). MITERRA-Europe has its own approach for handling N leaching and N surface runoff and does not use the default IPCC leaching factor of 30% of N input. Instead, leaching fractions are determined based on soil texture, land use, precipitation surplus, soil organic C content, temperature and rooting depth. Surface runoff fractions are calculated based on slope, land use, precipitation surplus, soil texture and soil depth (Velthof et al., 2009).

2.3. Input data

The main input data for MITERRA-Europe are crop areas, animal numbers and feed use at the NUTS-2 level. Crop areas and feed use are taken directly from CAPRI, which are based on Eurostat statistics. Animal numbers are from GAINS at a national level, and distributed over the NUTS-2 regions according to CAPRI livestock data. The reference year for our study was 2004, which is the current base year of CAPRI. All statistical input data are based on three-year averages of the period 2003–2005.

Table 1
Feed consumption in the EU-27, assigned feed properties and yield (average and range) per animal feed type.

Animal feed type	Feed use (Tg (DM)/yr)	DM content (g/g)	N content (g/kg DM)	P content (g/kg DM)	Average yield (t/ha)	Range in yield (t/ha)
Feed cereals	140.1	0.85	20	3.8	4.4	1.1–8.0
Protein rich feed	61.0	0.85	50	7.0	2.5	
Energy rich feed	9.6	0.85	12	3.4	5.0	
Grass	153.6	0.20	23–28	4.0	21.9	15.6–43.7
Forage maize	54.3	0.30	13	2.0	34.1	7.2–52.9
Other forage on arable land	59.5	0.30	25	3.0	24.1	4.7–42.8
Root crops	2.4	0.20	20	5.0	26.3	13.4–44.6
Milk for feeding	0.7	0.10	55	10.0	–	
Feed from dairy products	1.6	0.95	55	8.0	–	
Other feed	10.8	0.85	20	3.5	5.0	
Straw	16.1	0.85	5	1.0	–	

Source: Based on FAOSTAT crop yield data and Velthof et al. (2009).
DM, dry matter.

2.3.1. Feed use

The amount of animal feed and forage utilized in the EU-27 are in Table 1. Feed input/animal category was derived from CAPRI data. The feed and forage categories included in CAPRI are feed cereals, protein rich feeds (*e.g.*, soybean meal), energy rich feeds (*e.g.*, cassava meal, sugar beet molasses), maize and grass forages from arable land, straw, feed arising from dairy products (*e.g.*, whey, milk), and by-product feeds (*e.g.*, citrus pulp). Feed allocation considered nutrient and energy requirements of the animal, as well as the regional availability of feeds and feed demand based on national statistics derived from trade balances. Finally, input coefficients with feed prices had to result in feed costs for livestock production that were realistic within the specific geographical region. We assumed the composition of each feed type to be equal among EU countries, except for grass, for which data from Velthof et al. (2009) allowed for varying N content of grass among countries.

2.3.2. Primary animal production

Data for EU-27 primary animal production were derived from FAO statistics at a national level. Table 2 shows the total animal primary production for EU-27 with some assigned properties. Animal products used are defined as whole fresh cow milk and eggs in shell following FAOSTAT definitions and edible meat for beef, pork and poultry. For conversion of carcass weight to edible meat, we used a fixed fraction of 0.9 for all animal types. For studies with other objectives (*e.g.*, assessment of different human diets), a comparison based on protein content would be more appropriate. As livestock are not always slaughtered in the same country as they are raised, corrections for export and import of live animals were made with emissions being assigned to the country where the animals were raised. Based on FAO statistics, we calculated net-export/import of live animals/country. This value was converted to meat products using country specific carcass weights and total animal meat production was adjusted accordingly.

To calculate GHG emissions in terms of animal products, or per sector, the amount of feed consumed had to be related to the land area that would be required for its production. For forage crops and feed cereals, the average yield of each crop within each country was used to determine land area required for production (Table 1). This approach was less applicable to feed concentrates as they are comprised of mixtures of crop products, and industrial food processing residues with a large portion of these feeds imported. For protein rich feed, we assumed fixed yield of DM of 2500 kg/ha representing the average soybean yield in Brazil and Argentina (Smaling et al., 2008). A yield of 5000 kg/ha was assumed for energy rich feed and other feed as they were assumed to be a mixture of cereals and root crops.

Feed conversion was defined as the amount of dry weight feed needed to produce 1 kg of animal product. Feed conversion was calculated by dividing the total amount of feed consumed by the total amount of animal product produced per sector. Surface area needed for feed and forage production/kg product was defined as the sum of the areas for the different feed and forage types per sector, divided by total amount of animal product produced per sector.

Table 2
Total animal production in the EU-27 and assigned properties of the animal products.

Product	Total production[a] (Gg)	Carcass fraction	N content (g/kg)	P content (g/kg)
Beef	8186	0.58	33	5.5
Cows' milk	149,310		5.5	1
Eggs	6665		19	1.8
Pork	21,914	0.75	25	5.5
Poultry	10,780	0.71	33	5.5

[a] For meat products expressed in carcass weight (Source: FAOSTAT).

2.4. GHG emission sources

CH_4 from enteric fermentation, CH_4 and N_2O from manure management, direct and indirect N_2O soil emissions, CO_2 from organic soils and liming as well as from fertilizer production and fossil fuel use were included in the model as emission sources. All emissions were converted to CO_2-eq using most recent estimates of 100 years global warming potential (GWP) values (IPCC, 2007), which are for CH_4 and N_2O 25 and 298 times the GWP of CO_2, respectively.

2.4.1. Enteric and manure emissions

CH_4 emissions from enteric fermentation in ruminants were calculated using Tier 1 emission factors (EF) derived from IPCC (2006). For dairy cows, EFs were 109 and 89 kg CH_4/animal/yr, for beef cattle 57 and 58 kg CH_4/animal/yr, and for pigs 1.5 and 1.0 kg CH_4/animal/yr in Western Europe and Eastern Europe, respectively. For CH_4 emissions from manure management, IPCC (2006) emission factors were used which depend on animal type, average annual temperature and manure system. These were made country specific on the basis of the average annual temperature. For N_2O emissions from manure, emission factors were based on IPCC (2006) of 0.1% for liquid manure systems for cattle and pigs, 0.5% for solid manure systems for cattle and pigs and 0.1% for poultry manure. These emission factors were multiplied by country specific N excretion levels as estimated by GAINS (Klimont and Brink, 2004).

2.4.2. N_2O soil emissions

The N_2O emissions from agricultural soils consist of direct soil emissions from application of N fertilizer and animal manure, crop residues and cultivation of organic soils, urine and faeces produced during grazing, and indirect emissions from N leaching and runoff as well as from atmospheric deposition of N volatilised from managed soils. The N_2O emissions were calculated from IPCC (2006) EF. Direct N_2O soil emissions were calculated for each feed crop type (*i.e.,* grass, forage maize, other forage, feed cereals, root crops, soybean, canola, pulses). Emissions due to grazing were all attributed to grassland. For mineral fertilizer, applied manure and crop residues, the EF was 1%, whereas for grazing it was 2%. Indirect N_2O emissions from leaching and runoff (EF = 0.75%) and from atmospheric deposition of N volatilised from managed soils (EF = 1.0%) were not crop specific, but calculated for the NUTS-2 region and attributed to the feed crops based on their relative crop share.

To estimate N_2O soil emissions related to production of protein rich feeds, a distinction was made between soybean meal, canola meal and other protein rich feeds. Proportion of these three feed types was based on FAO production and trade statistics. Net import of soybean meal, assumed to be 80% of soybean weight, and canola meal, assumed to be 65% of canola weight, was calculated for each country and added to the amount produced in each country. Since most soybean meal is imported into Europe, no N_2O soil emission data were available, hence we calculated these emissions based on Smaling et al. (2008). The average soybean yield in Brazil, from which the EU imported most soybeans in 2005, was 2500 kg/ha, the N content of the harvested product was 58 g N/kg, the N index (ratio between N in harvested product and crop residue) was 3.8, and about 7 kg fertilizer N/ha was applied, resulting in an N input of ∼45 kg N/ha. With indirect emissions, this resulted in total N_2O soil emission from soybean of about 0.6 kg N/ha/yr. We did not include N_2O emissions from biological N fixation by soybean as Rochette and Janzen (2005) have shown that biological N fixation may not be an important source of N_2O.

2.4.3. Organic soils and liming

Drainage and tillage of organic soils leads to loss of C due to accelerated organic matter decomposition. The CO_2 emissions from organic soils were calculated using IPCC (2006) EF which distinguish arable land from grassland. The area of agricultural organic soils under grassland and arable land was derived by overlaying the CLC2000 land cover map (EEA, 2005) with the European soil map. In addition, we included CO_2 emissions from liming and urea application based on the carbon content and IPCC (2006) EF for these soil additives.

2.4.4. Fertilizer production

Mineral N fertilizer production is energy intensive and N_2O is emitted during nitric acid production. Kongshaug (1998) estimated that fertilizer production accounts for ∼1.2% of total global GHG emissions. Using information compiled by Brentrup and Palliere (2008), emissions from fertilizer production were estimated at 1.6 kg CO_2-eq/kg N for urea, 6.4 kg CO_2-eq/kg N for other N fertilizers and 3.1 kg CO_2-eq/kg P for phosphate fertilizers.

2.4.5. Fossil fuel and electricity use

No country specific data were available for fossil fuel use in agriculture. Instead, we made an estimate based on Nielsen and Luoma (2000) using an EU average value of 100 L of diesel/ha/yr for cereals and 145 L/ha/yr for root crops. Additionally, we estimated that 20 L of diesel is used/ha/yr for grassland and 50 L/ha/yr for other forage crops. However, as we knew that level of mechanisation differed among countries, the aforementioned average values were multiplied by the ratio of the specific country crop yield to the average EU-27 crop yield. An EF of 2.62 kg CO_2/L of diesel fuel was used (IPCC, 2006).

For electricity use in livestock housing systems we used data from CAPRI in which electricity use/animal activity level (*i.e.,* housing basis) was determined on the basis of methodology described by Kränzlein (2008). Electricity consumption levels were quantified using a normative approach in which a distinction was made between animal types as well as grouping EU

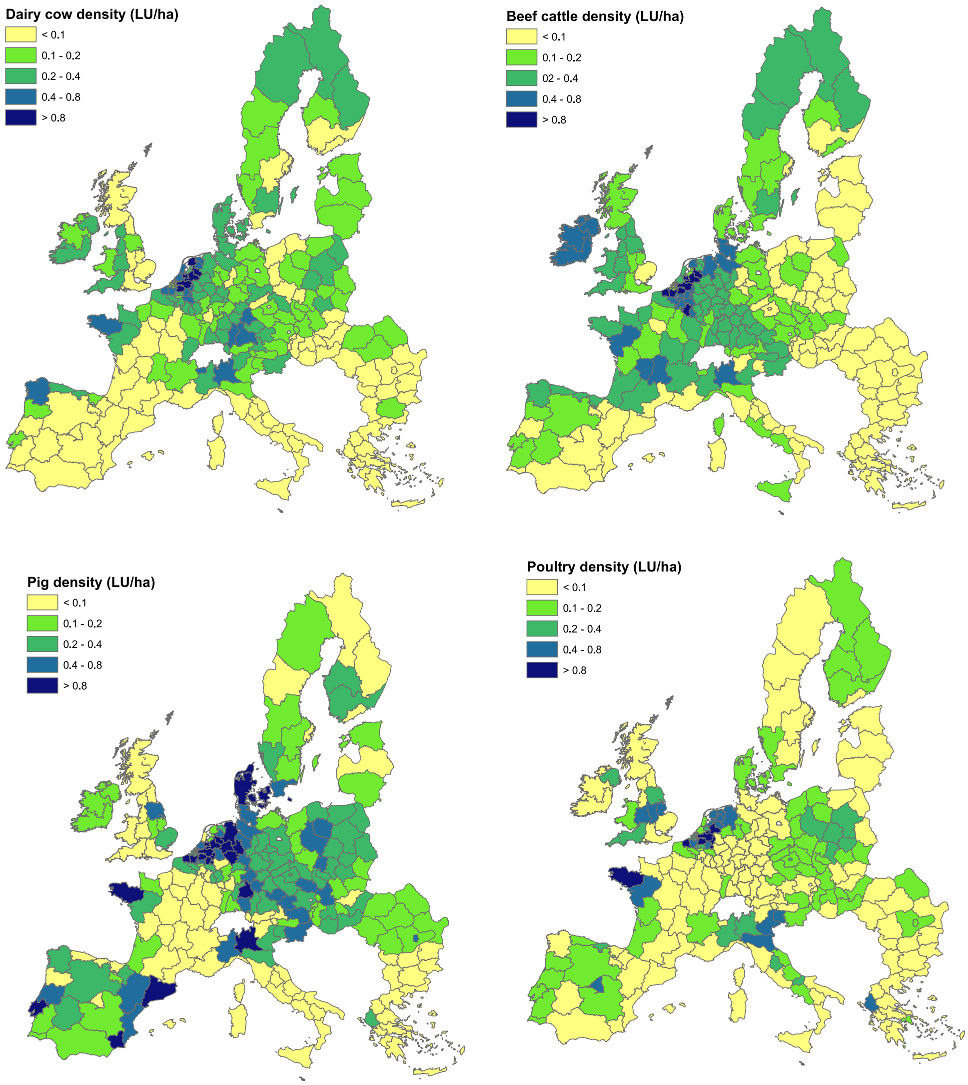

Fig. 2. Distribution of the main livestock types in the EU-27. Animal density is expressed in livestock units (LU) per ha UAA, in which the relative weight of a mature dairy cow is set at 1 and the other livestock categories at 0.5 for beef cattle, 0.35 for pigs, 0.012 for laying hens and 0.018 for other poultry, respectively.

countries based on needs for heating and cooling depending on average annual temperatures. Subsequently, electricity use was converted to CO_2 using an average country specific CO_2 EF for primary energy supply (IAE, 2010).

3. Results

3.1. Overview of European livestock systems

Fig. 2 shows the distribution of the main livestock types in the EU-27 as calculated by MITERRA-Europe on the basis of CAPRI data. Cattle production, both dairy and beef, is most intensive in The Netherlands and Belgium, and also in some regions of Germany, France, Austria and Ireland. Intensive pig farming is more dispersed with the highest densities in Denmark, Germany, The Netherlands, Belgium and Spain, and in some regions of France and Italy. Large scale intensive poultry farming mainly occurs in Belgium, The Netherlands and the Bretagne region of France.

On average, 72% of the total land area utilized for agriculture (*i.e.,* 188 million ha) was used for animal feed and forage production (Fig. 3). In Ireland, the western part of the United Kingdom and some regions of Austria, France and Spain, more than 90% of the agricultural area was linked to livestock production. About 65 million ha (*i.e.,* 35% of agricultural land) of this was grassland, of which about 24 million ha was unimproved. Further, ~60 million ha, or 32%, of agricultural land was used for cereal crop production for livestock with a large portion of livestock feed being imported.

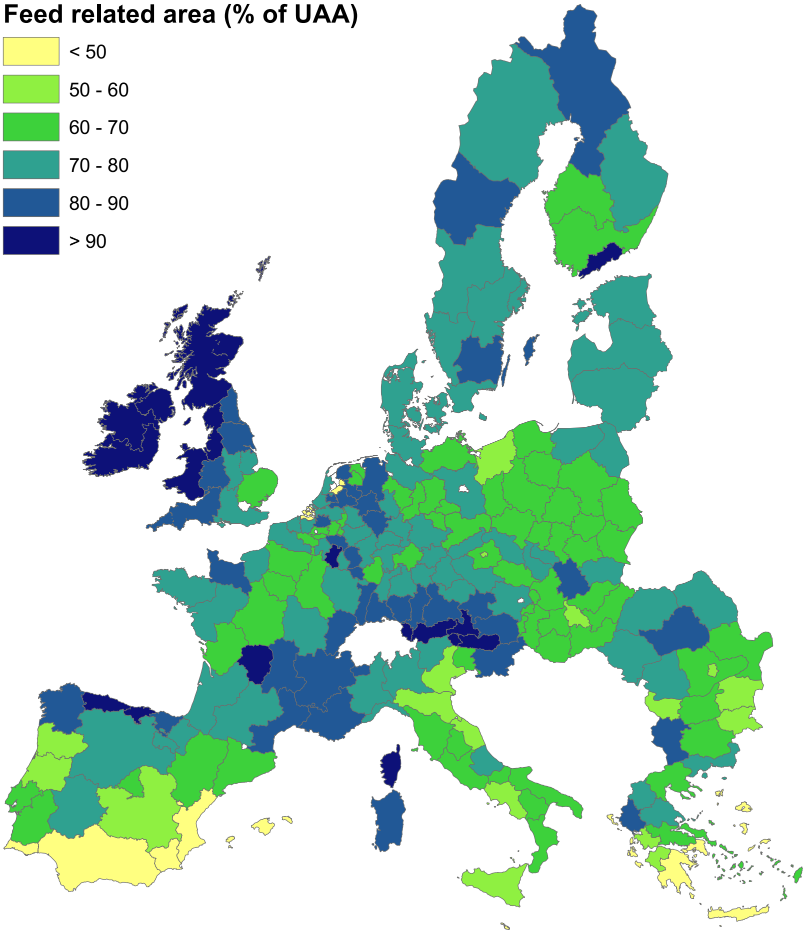

Fig. 3. Land area utilized for animal feed production as percentage of total utilized agricultural area (UAA) within EU-27.

3.2. *Feed conversion and surface area for feed and forage production*

A large fraction of the GHG emissions from livestock production relate to cultivation of animal feeds, especially N_2O emissions from soils. The surface area of land used for animal feed and forage production was calculated for each livestock sector based on current locations of feed production (Fig. 4). Grass, feed cereals and protein rich feeds used the largest land area. Cattle were predominantly kept on a grass and forage maize based diet, supplemented with feed concentrates in mixed systems, whereas pigs and poultry are fed cereals and concentrates. The total land area needed for feed cereals was estimated at 42 million ha and for grass ~33 million ha. Most of the animal feed and forage used for livestock production was grown in the EU-27, which is nearly self sufficient in cereal production and relies heavily on grass and forage for ruminant production. However, soybean and soybean meal, cassava meal, various corn products and citrus pulps are to large extent imported. Thus, part of the land area for feed production in Fig. 4 was not part of the EU-27.

Calculated feed conversion ratios, surface areas and GHG emissions/kg product for the sectors are in Table 3 for the EU-27. About 1.2 kg of feed/kg milk, 19.8 kg feed/kg beef, 4.1 kg of feed/kg pork, 3.3 kg feed/kg poultry and 2.8 kg feed/kg eggs were

Table 3
Feed conversion ratio (mass of dry weight feed consumed per mass of product produced), surface area for feed and forage, and GHG emission/kg product for the EU-27.

Product	Feed conversion ratio (kg feed/kg product)	Surface area for feed and forage (m^2/kg product)	GHG emission (kg CO_2-eq/kg product)
Cows' milk	1.2	2.4	1.3
Beef	19.8	37.3	22.6
Pork	4.1	11.7	3.5
Poultry	3.3	9.2	1.6
Eggs	2.8	9.0	1.7

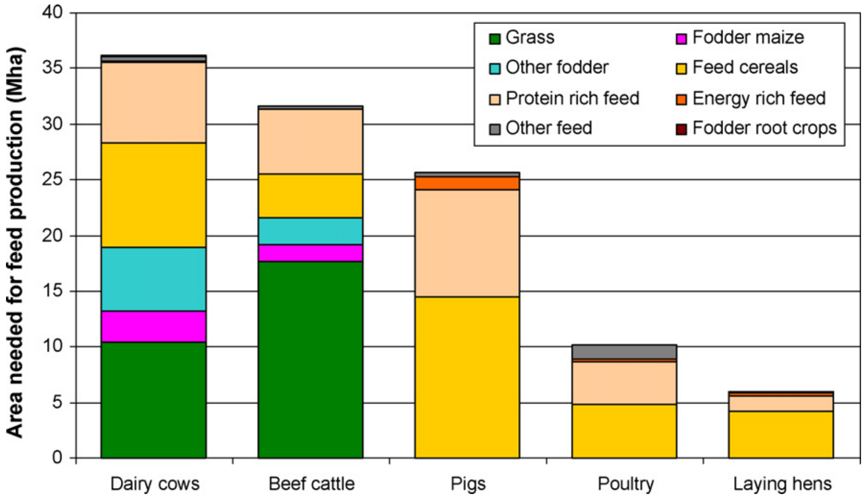

Fig. 4. Total feed area for each of the livestock sectors in the EU-27.

required to produce these products in the EU-27. However, large differences in feed conversion ratios occurred for individual countries. The surface area of land needed for production of milk, beef, pork, poultry and eggs was inversely related to the amount of feed required to produce a kg of product. The largest agricultural area was required for beef, followed by pork and poultry, with the least agricultural area (*i.e.,* 2.4 m^2) required to produce a kg of milk.

3.3. GHG emissions

Table 3 shows that beef had the highest emission with 22.6 kg CO_2-eq/kg, followed by pork at 3.5 kg CO_2-eq/kg, eggs at 1.7 kg CO_2-eq/kg, poultry at 1.6 kg CO_2-eq/kg and milk at 1.3 kg CO_2-eq/kg for the EU-27. This is also illustrated in Fig. 5 which shows GHG emissions/kg product for individual countries. The line in each graph indicates the average emission for the EU-27. Results indicate that differences among countries in GHG emissions related to beef production are largest in absolute terms but, in relative terms, emissions among countries in the poultry sector are largest. Also, GHG emissions for the other sectors vary among countries by a factor of two or more.

In addition to emissions/kg product, the share of various livestock production sectors to total GHG emissions is in Fig. 6. Countries with high GHG emissions per product should put more emphasis on mitigation of those sectors accounting for the highest share of GHG emissions. Countries are ordered according to the magnitude of total livestock GHG emissions with Germany and France having by far the highest total GHG emissions at 80 Tg CO_2-eq/yr (*i.e.,* 17% of EU-27 total) for both countries (Fig. 6). For most countries, the dairy and beef sectors accounted for the largest share of GHG emissions. In Denmark, the pig sector accounted for the largest share of total emissions while, in Hungary and Greece, poultry accounted for a substantial proportion of GHG emissions.

Summarized by sector, the largest livestock related GHG emissions in the EU were from dairy followed by beef (Fig. 7). Together, these sectors account for more than 70% of GHG emissions from livestock production. The GHG emission from the pig sector was about 16%, whereas the poultry sectors was about 6%.

The two GHG emission sources which have relatively large contributions are CH_4 emissions from enteric fermentation at 36% and N_2O emission from soils at 28%. GHG emissions from manure storage accounted for 13%, fertilizer production 11%, cultivation of organic soils and liming 7%, fossil fuel use 3.2% and electricity 3.2% of total GHG emissions from livestock production. Contribution of emission sources within the dairy sector to total GHG emission differs substantially among countries (Fig. 8).

4. Discussion

Total GHG emissions from livestock farming in the EU-27 were 493 Tg CO_2-eq/yr, which corresponds to about 10% of total EU-27 GHG emissions as reported to UNFCCC, which were 5148 Tg CO_2-eq excluding net CO_2 removals from land use, land use change and forestry for 2004 (EEA, 2009). When we include GHG emissions from the sheep and goat sector and arable sector (*i.e.*, non-feed crops) total calculated GHG emissions from agriculture were 616 Tg CO_2-eq/yr. For various reasons this value is higher than the 481 Tg CO_2-eq (EEA, 2009) reported for total emissions from the agricultural sector in 2004. This latter figure was based on National Inventory Reports as supplied by member states. Not all categories included in our estimate are classified in the 'agriculture' category. For example, emissions related to production of mineral fertilizer (73 Tg CO_2-eq) are included in the 'industry' category, those associated with cultivation of organic soils and liming (51 Tg CO_2-eq) are included in the 'LULUCF' category, and emissions from fossil fuels used for operation of agricultural machinery (28 Tg CO_2-eq)

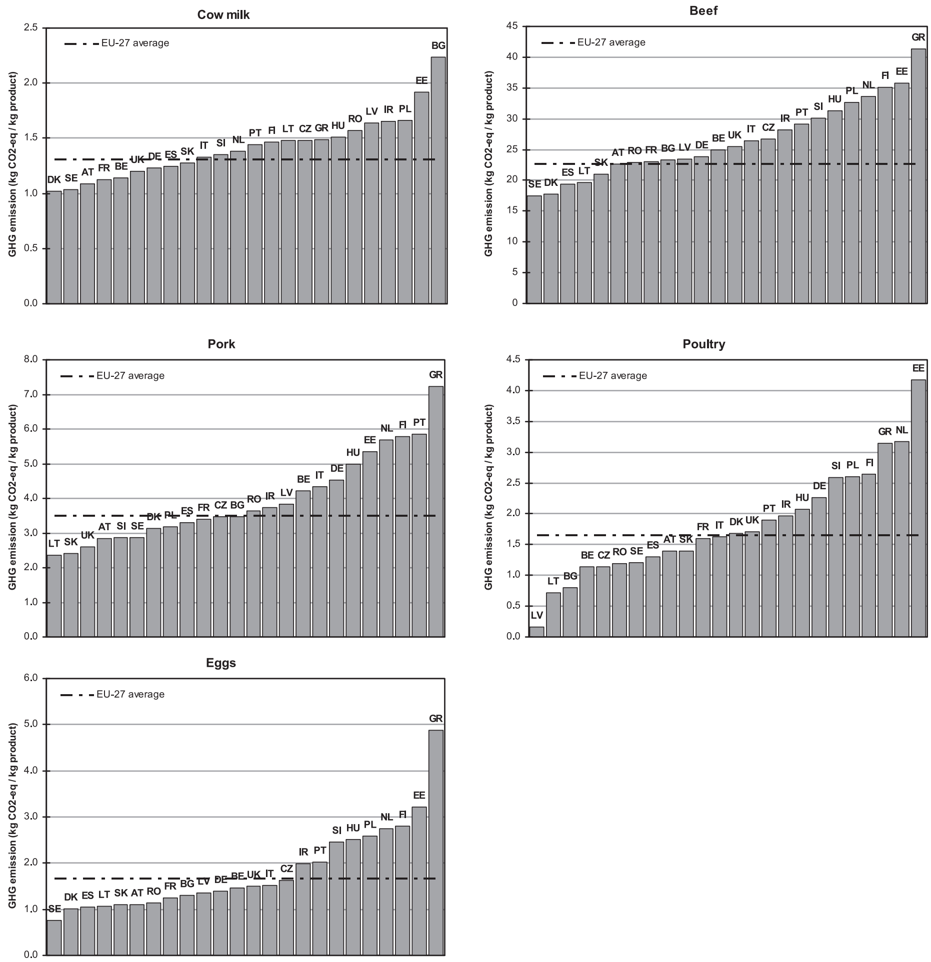

Fig. 5. GHG emissions/kg of animal product for EU member states (Cyprus, Luxembourg and Malta are not included). ISO 2 digit codes are used for the country abbreviations.

and generation of electricity (17 Tg CO_2-eq) are included in the ‘energy’ category. Moreover, most national inventories are based on IPCC (1996) guidelines, whereas we used the latest IPCC (2006) guidelines which result in different EF and global warming potential values. When these differences are considered, total GHG emissions as calculated by MITERRA-Europe are consistent with the reported GHG emissions as described by Lesschen et al. (2009).

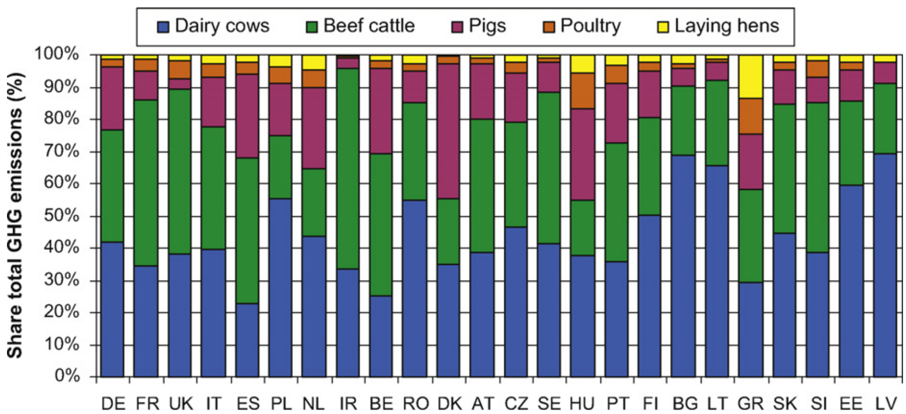

Fig. 6. Share of the different sectors of livestock production in total agricultural greenhouse gas emissions from each country. The countries on the *x*-axis are ordered according to the magnitude of greenhouse gas emissions.

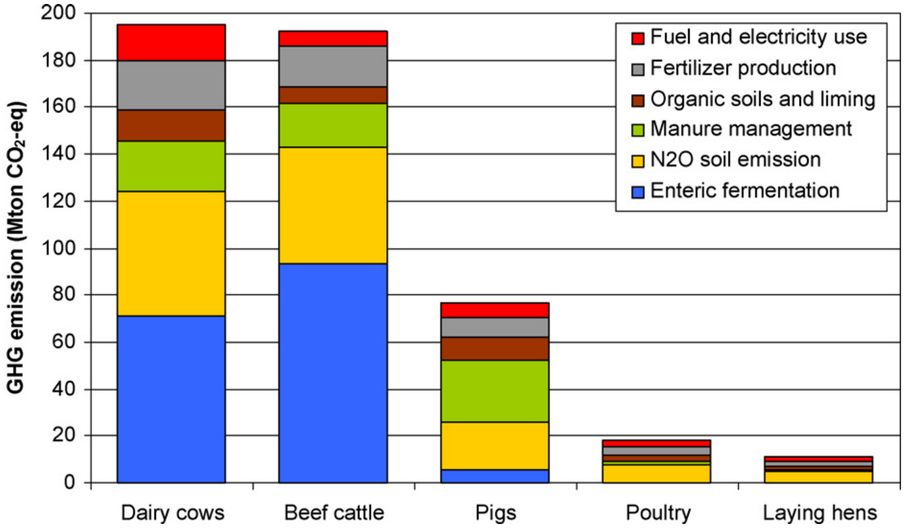

Fig. 7. Total greenhouse gas emissions from the various emission sources associated with livestock production in the EU-27.

We included GHG emissions related to cultivation of soybeans in South America that are imported into the EU (*i.e.*, N_2O soil emissions, fossil fuel use, fertilizer production). However, emissions caused by direct or indirect land use change, such as deforestation in Brazil or conversion of pasture and scrubland in Argentina, were not included given the complexity of the processes, drivers and sectors involved (Geist and Lambin, 2002; Fearnside, 2008). FAO (2010) proposed that emissions related to land use change should be attributed to soybean cultivation, and estimated average land use change emission of 0.93 kg CO_2-eq/kg soybean meal for Argentina and 7.69 kg CO_2-eq/kg for Brazil. If we were to adopt the same method, this would add an additional 134 Tg CO_2-eq/yr to our emissions estimates, or a 25% increase in total GHG emission associated with livestock production in the EU-27.

4.1. Regional differences

A benefit of our approach was that a uniform methodology was applied to all countries allowing for direct comparison of GHG emissions among countries. For example, of Europe's four largest beef producers, France, Germany, Italy and the UK, UK produced 47% more GHG/kg beef than France, 58% more than Germany and 70% more than Italy. Main components that cause the relatively high GHG emissions/kg beef in the UK are enteric fermentation, N_2O soil emissions and CO_2 from fertilizer production. The older age of slaughter and reliance on pasture based production systems with high fertilizer application

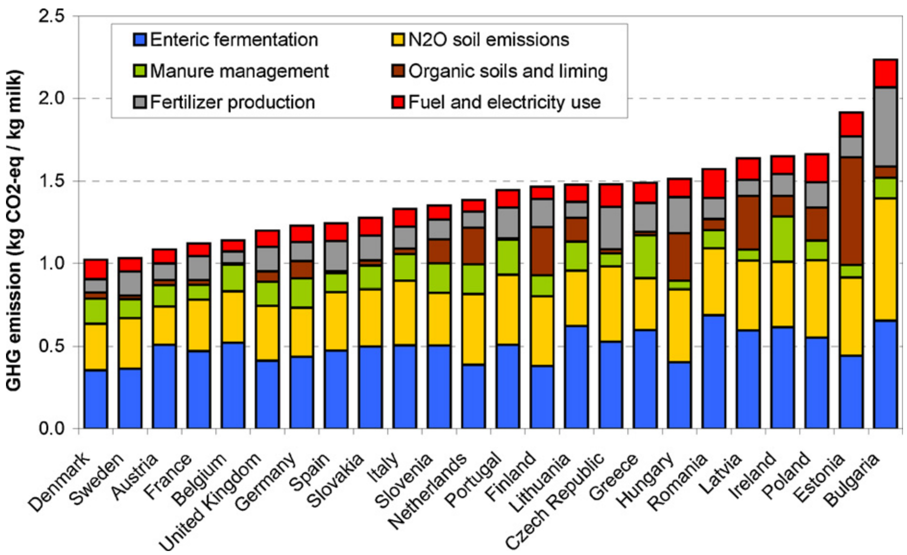

Fig. 8. GHG emission per kg milk within EU countries as it relates to emission sources.

explain these higher emissions in the UK. Italy produces about the same amount of beef as the UK, but on a much smaller land area as cattle are slaughtered at a younger age and grasslands are fertilized less. This is also reflected in feed consumption differences as, in Italy, 20% of dry weight feed intake of cattle is as cereals *versus* 1% in the United Kingdom. France has a much higher level of pasture based beef production than Germany or Italy. Yet, while total grassland area of France is similar to that of the UK, total N_2O soil emissions are almost twice as high. However its beef output is almost 3 fold higher, thereby explaining lower GHG emissions/kg beef for France.

To illustrate regional differences, we selected the GHG emission/kg milk (Fig. 5) and included the contribution of each emission source. Results, in Fig. 8, show that there is no single emission source responsible for the difference in emissions/kg milk among countries. Variations in emissions from organic soils is one factor responsible for differences among countries, as they are substantially higher for the Baltic states, the Netherlands, Hungary, Poland and Finland. For enteric fermentation, the main GHG source, differences among countries are lowest, but there is still almost a 2-fold difference between the country with the lowest (Denmark) and highest (Romania) emissions, which are mainly related to differences in efficiencies (*i.e.*, milk yields/cow), which are much lower in Romania.

4.2. Comparison with other studies

Several studies have been completed to assess GHG emissions of livestock product production, most of them using life cycle assessments (LCA). Weidema et al. (2008) assessed impacts of meat and dairy product production based in the EU based on a range of environmental indicators using a LCA system model. GHG emissions associated with production of meat (*i.e.,* beef, pork, poultry) and dairy products in the EU-27 were 670 Tg CO_2-eq. The dairy sector was the largest emitter with 41%, followed by beef with 28%, pork with 26% and poultry with 5% (Weidema et al., 2008). On a product basis, GHG emissions for milk were 2.4 kg CO_2-eq/kg, for beef 28.7 kg CO_2-eq/kg, for pork 11.2 kg CO_2-eq/kg, and for poultry 3.6 kg CO_2-eq/kg. Although system boundaries (*e.g.,* processing and consumption of livestock products) are included and calculation methods differ somewhat, results generally agree with our findings.

de Vries and de Boer (2010) reviewed LCA based studies to assess environmental impacts of livestock product production. Based on 16 studies from OECD countries, ranges of GHG emissions were reported for production of 1 kg of product being: 0.84–1.3 CO_2-eq for milk, 14–32 kg CO_2-eq for beef, 3.9–10 kg CO_2-eq for pork, 3.7–6.9 kg CO_2-eq for poultry and 3.9–4.9 CO_2-eq for eggs. For milk and beef, our results are within ranges of de Vries and de Boer (2010) but, for pork and poultry, our per product emissions are lower. This could be due to different system boundaries, allocation based on prices as used in the LCA studies, and exclusion of the upstream part of the food chain (*i.e.,* transport and processing) in our assessment.

Casey and Holden (2005) calculated an average emission of 1.46 kg CO_2-eq/kg milk and 19.4 kg CO_2-eq/kg beef in Ireland (Casey and Holden, 2006). Nguyen et al. (2010a) found an average GHG emission of 4.6 kg CO_2-eq/kg meat for pigs in NW Europe using the same system boundaries as in our study, and Nguyen et al. (2010b) calculated GHG emissions of 16.0–27.3 kg CO_2-eq/kg beef for various beef farming systems in Europe. Our results are comparable with these studies, in spite of differences in approach, system boundaries and calculation methodologies. Whereas LCA based studies can be considered as bottom-up approaches for default farms in most cases, our approach can be considered as top-down in which the total amount of feed and GHG emissions are allocated to different sectors. For Sweden (Cederberg et al., 2009) and the UK (Williams et al., 2006), a similar top-down approach was used at the national level. Ideally, both approaches should lead to similar results.

4.3. Uncertainties

To have confidence in outcomes of environmental impact assessments, it is important to have insight into related uncertainties. There are several sources of uncertainty, such as input data, system boundary definition and modelling assumptions. Consequently, differences in GHG emissions among countries may reflect errors in the databases used, especially in allocation of feeds to animal categories and cross-border transport of animals, feed and livestock products. Particularly, statistics on trade of live animals seem to be very uncertain and might lead to systematic errors for countries importing young animals and exporting mature animals, a distinction which is not provided by FAO trade statistics. For example, The Netherlands exports piglets and imports beef calves. In Fig. 5, an example of such a cross-border error is evident for poultry. Estonia appears to have by far the highest GHG emissions/kg meat, while neighbouring Latvia has the lowest emissions. Part of the poultry raised in Estonia, however, is slaughtered in Latvia, which is not fully covered by statistics on export and import of live animals. This may result in underestimation of GHG emissions/kg meat for Latvia and overestimation for Estonia.

A clear definition of system boundaries is important to allow comparison with other studies. However these system boundaries or functional units, as used in LCA studies, often differ due to data availability or study objectives (de Vries and de Boer, 2010). For example, it is difficult to determine how GHG emissions are distributed between dairy and beef farming. In our approach, emissions from all calves and heifers were attributed to beef. Conversely, emissions from dairy cows were attributed entirely to dairy, even though dairy cows also supply meat. Other approaches to allocating emissions to meat and milk also exist. For example, Casey and Holden (2005) attributed 96.5% of the GHG emissions to milk using mass allocation for dairy cattle, while economic allocation only attributed 85% to milk and 15% to meat thereby illustrating that comparing results among studies is difficult and must be done with caution. However, our approach is suitable for comparisons among countries since the same system boundaries and calculation parameters were consistently applied to all EU-27 member states. Moreover, our top-down approach will have a lower uncertainty at EU-27 level compared to LCA based studies. Up-scaling of LCA based results can easily result in over- or underestimation of total emissions at EU level, whereas in our top-down approach the total land use and GHG emissions are relatively fixed and uncertainty is mainly in allocation among the livestock sectors and countries.

4.4. GHG mitigation in livestock production

In EU-27, cattle, pig, and poultry production are intensive, although there are large regional differences (Oenema et al., 2007; Velthof et al., 2009). These differences among countries suggest that production systems differ substantially in emissions and that there may be scope for mitigation of GHG emissions. Although GHG emissions within the agriculture sector in the EU-27 declined by more than 20% from 1990 to 2007 (EEA, 2009), this reduction was mainly due to declining livestock populations, especially dairy cows. The main reasons for this decline were establishment of a milk quota, the economic collapse in Eastern Europe, and reduction in use of artificial N fertilizer due to implementation of the Nitrates Directive. However for further GHG reduction in the livestock sector more mitigations are needed. Garnett (2009) distinguished four approaches to mitigation in the livestock sector, which focus on improving productivity, changing the management system, managing outputs and reducing livestock numbers. For the first three approaches, technical measures can be applied whereas for the fourth approach structural changes will be required.

A number of options exist to reduce CH_4 emissions from ruminants and animal manure. CH_4 emissions from enteric fermentation may be reduced by modifications in diet, use of feed additives and breeding for livestock with lower emissions. CH_4 emissions from manure can also be reduced by optimized storage or by anaerobic digestion (Mosier et al., 1998; Monteny et al., 2006). There are also options to reduce emissions of N_2O from agricultural soils. Measures such as improved timing and matching of nutrient application to crop requirements can reduce emissions and reduce costs for farmers. There are also co-benefits with nutrient management policies that could lead to reduced water and air pollution (Smith et al., 2008).

Besides these technical measures, structural changes in livestock populations could also be implemented. A shift from a human diet with relatively large proportions of meat protein to plant derived protein products would appear to be environmentally more sustainable, technological feasible and socially desirable (Aiking et al., 2006). Several studies have demonstrated that a reduction in consumption of meat may benefit human health, as well as reduce GHG emissions and global land use for agriculture (Aiking et al., 2006; McMichael et al., 2007; Stehfest et al., 2009). If implemented at a global level, it would more than halve the agricultural land needed and eutrophication associated with food production (Aiking et al., 2006, Weidema et al., 2008).

5. Conclusions

Livestock farming has an impact on global warming with about 10% of total GHG emissions from the EU-27. This share would be larger if emissions from land use change as a result of soybean cultivation in Latin America and those associated with transport, processing and packing were included. Results show that the dairy cow and beef sectors have the largest absolute GHG emissions, with CH_4 from enteric fermentation and N_2O from agricultural soils being the most important sources. On a product basis, beef has by far the highest GHG emissions at 22.6 kg CO_2-eq/kg, followed by pork at 3.5 kg CO_2-eq/kg, poultry at 1.6 kg CO_2-eq/kg, eggs at 1.7 kg CO_2-eq/kg and milk at 1.3 kg CO_2-eq/kg. However large variations exist among countries, which are partially due to differences in animal production systems, feed types and nutrient use efficiencies by the animals. Our study provides insight into differences in efficiency and GHG emissions for animal production among regions of Europe and, based on these results, possible future development pathways towards more sustainable animal production which should be examined.

Conflict of interest

None.

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