Study on

Future of EU livestock: how to contribute to a sustainable agricultural sector?

Final report

This report has been prepared by Dr. Jean-Louis Peyraud (INRAE) and Dr. Michael MacLeod (SRUC).

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The United Kingdom withdrew from the European Union as of 1 February 2020. During the transition period, which ends on 31 December 2020, Union law, with a few limited exceptions, continues to be applicable to and in the United Kingdom and any reference to Member States in Union law shall be understood as including the United Kingdom.

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1.1. The economic importance of livestock and livestock products

The physical and financial scale of EU livestock production means that it has far-reaching environmental, economic and social consequences. Livestock production is an important part of the economy and vitality in many regions including some marginal rural areas. Its social importance extends beyond employment; many of the valued landscapes and cuisines of the EU have evolved along with livestock production. It also has negative impacts on the environment, through the consumptions of finite resources (land, water and energy) and the production of physical flows (such as nutrients, greenhouse gases, and toxic substances) that can impact on biodiversity, human health and ultimately the functioning of the ecosystems upon which we depend for food production. Livestock also produces a range of other goods and services.

1.1.1. Livestock play a key role in European agriculture production and economy

The livestock sector contributes substantially to the European economy. In 2017, the value of livestock production and livestock products in the EU-28 was equal to € 170 billion, representing 40% of the total agricultural activity[1]. The contribution of livestock to total agricultural activity is much higher in countries like Ireland (74.2%), Denmark (66.4%), UK (60.2%), and Belgium (58.9%). The milk sector topped the list (13.9%), followed by pork (8.9%), beef, sheep and goat (8.2%), poultry (5.0%) and eggs (2.4%).

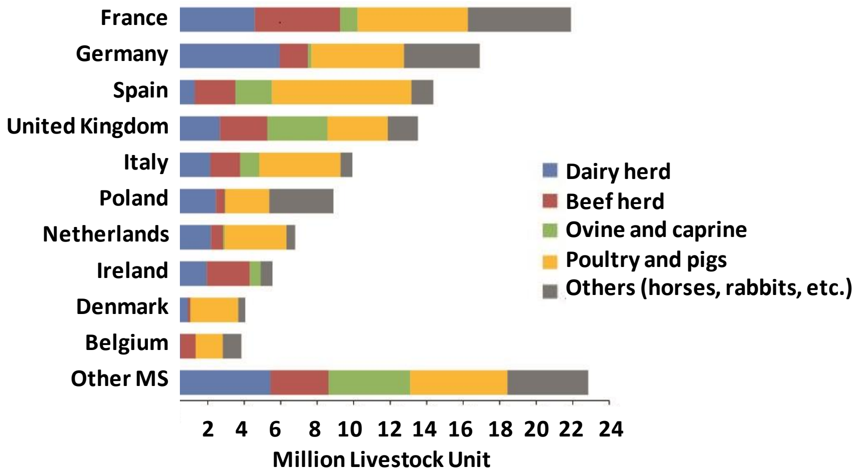
The EU-28 had 131 million livestock units in 2016[2] and more than 50% of these units were concentrated in four countries (Figure 1). Dairy and beef cattle represented more than 50% of the total European herd, the pig herd represented 25% and poultry 15%. The EU differs from other regions of the world by a greater relative rate of dairy and beef cattle and a lower relative rate of poultry. National and regional disparities are large. Dairy and beef cattle are the majority in 23 out of 28 member states, their share exceeds 80% in Luxembourg and Ireland but it is less than 25% in Greece and Cyprus. The pig population is over 66% in Denmark and 33% in Belgium, Spain, Germany and Cyprus. Chickens represent 37% in Hungary and less than 2% in Ireland. The numbers of livestock units increased from 1960 to 1990, decreased between 1991 and 2014 and has slightly increased in recent years. In total, the EU today has far more pigs and poultry than in the

[1] European Commission, 2018. Agricultural and farm income. European Commission, Brussels, DG Agriculture and Rural Development, 27 p.

[2] Eurostat, 2019. Agri-environmental indicator – Livestock patterns. Eurostat, Statistics Explained, Data from January 2019, Online publication, https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-livestock_patterns#Livestock_density_at_EU_level_in_2016.

early 1960s (+ 55% for pigs), but fewer ruminants (- 6% cattle, -17% for sheep). The European bovine population represents 8% of world bovine population.

Figure 1: Breakdown of EU Livestock Units (GBUs) by Member States and species

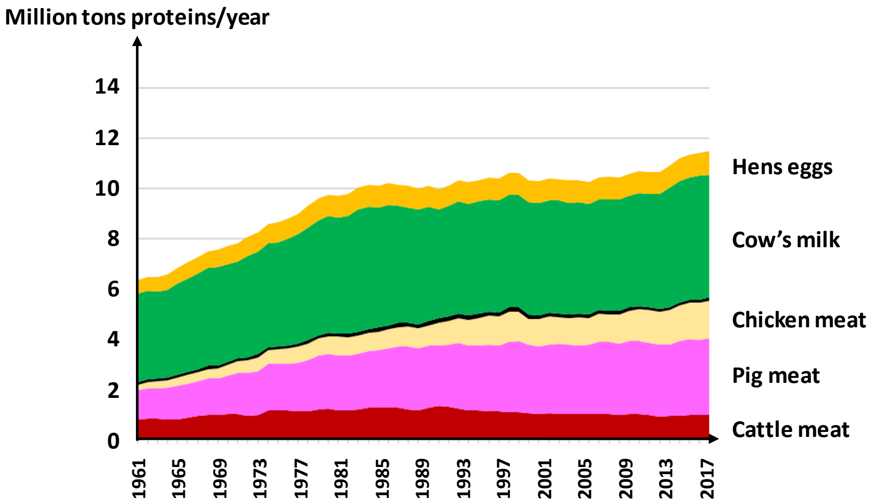


Source: Eurostat[2]

The EU-28 produced 47 million tonnes of meat in 2017, comprised of pig meat (50%), poultry meat (31%), beef (17%), and sheep and goat meat (2%)[3]. It is now the world's second largest producer of meat, far behind China but ahead of the United States. Meat production increased rapidly until the early 1990s, then pig and poultry production continued to grow but at a slower rate whereas volumes of beef, sheep and goats have been decreasing under the triple effect of a reduction in the number of livestock unit, lower efficiency gains than for monogastric animals and a more modest restructuring of the sector. Egg production increased by 60% between 1960 and 2014. Finally, the EU now produces around 160 million tonnes of milk, mainly (more than 90%) as cow's milk. This production increased by 30% between 1960 and 1984, then growth was far weaker during the years when this quota policy was active (from 1984 to 2014) and it has slightly increased since the abolition of milk quotas in 2015.

[3] Buckwell A., Nadeu E. 2018. What is the safe operating space for EU Livestock? RISE Foundation, Brussels, 108 p.

Figure 2. EU annual livestock protein production 1961-2018



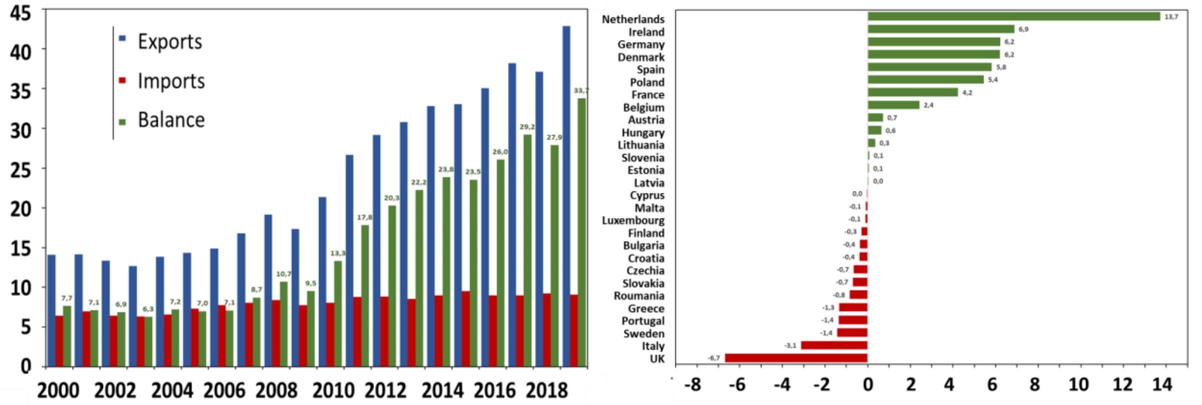
Source: FAO Stat, 2020

The EU-28 is a net exporter on the world market and the international trade surplus in livestock commodities has steadily increased since 2000, reaching € 33.7 billion in 2019 (Figure 3)[4]. The EU mainly exports dairy products (€ 22 billion in 2019) and pig products (€ 9.8 billion)[4]. The EU-28 also exports live animals (€ 2.6 billion)[5]. However, gross meat imports are significant (€ 4.1 billion) and might become more so once certain new trade agreements (in particular with Mercosur) come into effect. On the other hand, CETA and Ukraine are already implemented and the first years of CETA show an improvement of bilateral trade in beef. European production is carried out at higher costs and product prices than in many other exporting areas of the world, but they are based on non-price competitiveness linked to the criteria of product safety, traceability and generally quality. International trade is vital for certain member states such as Denmark, Ireland, the Netherlands, Germany and France. Intra-community trade is of equal or even greater importance than world trade, in a context of heightened competition between MS because of the sharp reduction in CAP market measures.

[4] Chatellier V., Dupraz P. 2019. Les performances économiques de l'élevage européen : de la « compétitivité coût » à la « compétitivité hors coût ». *INRA Prod Anim*., 32, 171-188.
Data form COMEXT, Treatment INRA SMART-LERECO, 2019.

[5] According Eurostat: https://ec.europa.eu/eurostat/statistics-explained/index.php/Extra-EU_trade_in_agricultural_goods#Agricultural_products:_3_main_groups.

Figure 3: Trade balance of the EU-28 (billion €) from 2000 to 2019 (left) and of each country in 2019 (right)[4]



Source: Chatellier et al., 2019[4]

1.1.2. Importance of livestock for employment and rural vitality

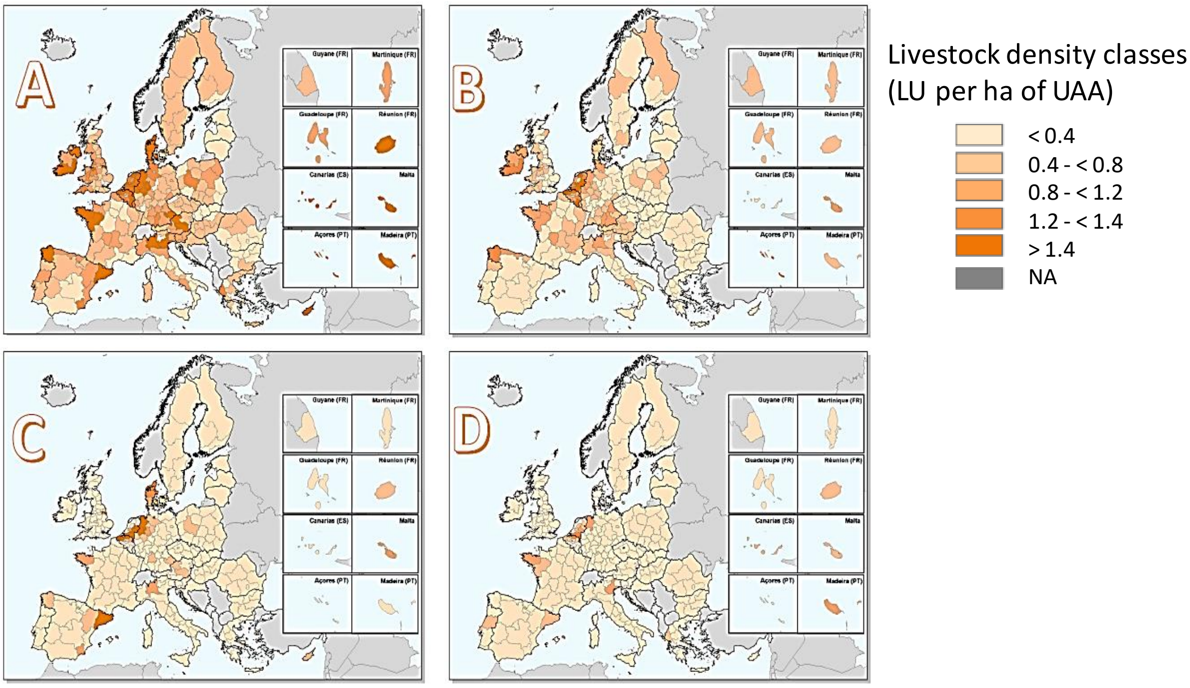
Livestock farming is of crucial importance for many European region and agriculture and 58% of European farms hold animals[2]. European livestock farms employ around 4 million people (salaried and non-salaried), 80% of whom reside in the more recent EU member-states. Mixed crop-and-livestock and dairy farms account for the largest share of jobs (37% and 25% respectively), far ahead of pig and poultry farms (8%), which are fewer in number but larger in size and have the largest percentage of salaried positions. Some geographical areas are highly dependent on such jobs, given the importance of animal production in the local economy. The average livestock farm typically has 1 to 2 workers. Therefore European livestock farm are neither mega farms with thousands/millions heads as bovine feedlot as in North America or industrial pig farms in China or new poultry farms in Ukraine nor small family farms as in developing countries. European industries linked to animal production (milk and meat processing, feed for livestock) have an annual turnover of approximately €400 billion (2013). Although the total number of companies is high, these agri-food sectors are dominated by a few large companies/cooperatives of global importance. Across all these sectors, the search for improvements in cost efficiency and differentiation based on quality and labelling programs play a key role in competitiveness.

Livestock are present in almost all regions of Europe. A third of all farm animals – especially dairy, pigs, and poultry – are concentrated within a small number of areas (Denmark, the Netherlands, Northern Germany, Western France)[6] (Figure 4). Intensities of production measured by the number of livestock units per ha (LU/ha), vary greatly from one member state to another, ranging from (in 2016) 0.2 livestock units in Bulgaria to 3.8 in the Netherlands. These national averages mask large regional disparities, in Spain and France in particular. Such variation

[6] C. Roguet C., Gaigné C., Chatellier V., Cariou S., Carlier5 M. Chenut R., Daniel K., Perrot C. 2015. Spécialisation territoriale et concentration des productions animales européennes : état des lieux et facteurs explicatifs. *INRA Prod. Anim.*, 28, 5-22.

often requires solutions tailored to a regional or even sub-regional scale[7]; there is no "one size fits all" optimal solution. In regions with a high proportion of grassland, the grazing livestock density index also varied greatly (see Figure 14). It ranges from 1.7 LU/ha in intensive grassland based system (Ireland, Netherlands, part of Bavaria, Galicia, etc.) that is nonetheless lower than that of high density areas with little grassland (2.6 LU/ha), to 0.5-1.0 LU/ha in intermediate zones (Massif Central, Austria, Wales, etc.) and to less than 0.3 LU/ha in low density zones (North of Scotland, Mediterranean zones, etc).

Figure 4: Livestock density within the European Union in 2016 for: (a) all livestock, (b) all bovines, (c) pigs and (d) poultry. Estimated by dividing the number of livestock units by the utilised agricultural area (UAA) within each NUTS 2 region.



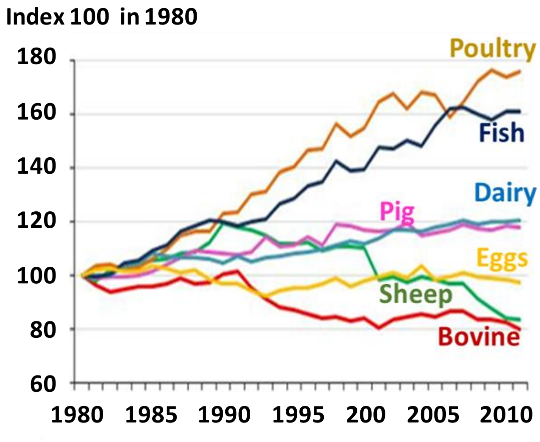
Source: Eurostat, March 2020; maps created by Matteo Sposato, SRUC

[7] Dumont B. (coord), Dupraz P. (coord.), Aubin J., Batka M., Beldame D., Boixadera J., Bousquet-Melou A., Benoit M., Bouamra-Mechemache Z., Chatellier V., Corson M., Delaby L., Delfosse C., Donnars C., Dourmad J.Y., Duru M., Edouard N., Fourat E., Frappier L., Friant-Perrot M., Gaigné C., Girard A., Guichet J.L., Haddad N., Havlik P., Hercule J., Hostiou N., Huguenin-Elie O., Klumpp K., Langlais A., Lemauviel-Lavenant S., Le Perchec S., Lepiller O., Letort E., Levert F., Martin, B., Méda B., Mognard E.L., MouginC., Ortiz C., Piet L., Pineau T., Ryschawy J., Sabatier R., Turolla S., Veissier I., Verrier E., Vollet D., van der Werf H., Wilfart A. (2016). Expertise scientifique collective: Rôles, impacts et services issus des élevages en Europe. Rapport Inra (France), 1032 p. www.inrae.fr/sites/default/files/pdf/esco-elevage-eu-rapport-complet-en-francais.doc.pdf

1.1.3. European consumption of animal products in perspective

Europeans consume large quantities of animal products per capita. Protein of animal origin covers over 50% of the total protein intake of European diets[8] and EU27 per capita consumption is more than twice the world average, though still less than in North America (Figure 5). In 2020, each European consumed 69.5 kilograms of meat annually expressed in retail weight equivalent and 236 kilograms of milk in litres of milk equivalent[9]. Pork was in first place (31.3 kg) followed by poultry (25.6 kg) and ruminant meat (10.8 for beef and 1.8 kg for sheepmeat). EU meat and dairy consumption per capita increased for several decades before starting to decline in recent years (Figure 5). Meat consumption is expected to decline further by 2030[9]. The decline is accompanied by a shift in the consumer basket with a decrease in beef consumption and an ongoing replacement of pigmeat by poultry meat. EU-wide average figures mask significant national disparities, for both meat and milk, in terms of current consumption and trends over time. This heterogeneity can be illustrated by noting that the annual consumption per capita varies for meat from 34 kilograms in Bulgaria to 62 kilograms in Luxembourg, for milk from 115 kilograms in Cyprus to 353 kilograms in Finland. Since 2011, there have been significant drops in meat consumption in Italy (-8 kg), Germany (-10 kg), and Belgium (-26 kg) but smaller changes in France over the same period, although there has been a shift from red meat to poultry meat.

Figure 5: Evolution of consumption of animal products per person in the EU-28



Source: Dumont et al, 2016[7]

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[8] Westhoek H., Lesschen J.P., Leip A., Rood T., Wagner S., De Marco A., Murphy-Bokern D., Pallière C., Howard C.M., Oenema O., Sutton M.A. 2015. Nitrogen on the table: The influence of food choices on nitrogen emissions and the European environment. European Nitrogen Assessment Special Report on Nitrogen and Food, Centre for Ecology & Hydrology, Edinburgh, UK, 70 p.

[9] EC 2019. EU Agricultural Outlook for market income 2019-2030. European Commission DG Agriculture and Rural Development. Brussels.

1.1.4. European Livestock and meat consumption in a global food security perspective

While consumption in the EU stagnates or tends to decrease, the global demand is expected to sharply increase[10] for major livestock commodities between now and 2050. World demand for meat should increase by + 15% over the next ten years to be close to 38 kilograms per person per year in 2027[11], for a largely in the form of poultry and pork. FAO estimates that demand is expected to increase by 200 million tonnes between 2010 and 2050. Global consumption of milk and dairy products would increase by about 25% by 2027, mainly in the form of fresh dairy products[7].

Feeding the world in 2050 by offering all healthy, balanced diets and respecting the environment is a huge challenge. Meeting this challenge requires acting simultaneously on the demand side and supply sides. It may require decreases in the amount of livestock commodities consumed by some people (OECD countries) and increases in others (particularly the poor in sub-Saharan Africa and South Asia)[12]. Losses and waste also need to be reduced along the production, processing, distribution and consumption chain. World food security could be improved by reducing overconsumption (relative to dietary requirements) of animal products[13]. However it should be noted that much of the challenge needs to be met in Asia where 47% of the world's meat is currently consumed (including 27% in China but only 2% in India) and consumption per capita is increasing. The EU accounts for 15% or world meat consumption (19% including Russia), which is similar to North America, while Africa consumes only 6%[14]. In relation to the uneven growth of supply and demand across the different regions of the globe, the future is likely to see a continuation of the net export of animals, animal products and livestock feed materials from South and North America, Europe and Oceania to Asia and Africa[15].

[10] Alexandratos N., Bruinsma J. 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Working paper No. 12-03. Rome, FAO.

[11] Organisation for Economic Cooperation and Development, Food and Agriculture Organization of the United States, 2018. OECD-FAO Agricultural Outlook 2018-2027. OECD, Paris, FAO, Rome, 112 p.

[12] Mora O., de Lattre-Gasquet M., Le Mouël C. 2018. Land Use and Food Security in 2050: A narrow road - Agrimonde-Terra. Editions Quae, Paris, Collection Matière à débattre, Paris, 400 p.

[13] WRI (World Resources Institute), 2018. Creating a sustainable food future: A menu of solutions to feed nearly 10 billion people by 2050. WRI, World Resources Report, Synthesis Report, December 2018, 96 p.

Guyomard H., Darcy-Vrillon B., Esnouf C., Marin M., Russel M., Guillou M., 2012. Eating patterns and food systems: Critical knowledge requirements for policy design and implementation. *Agri. Food Security* 2012: 1-13.

[14] OCDE-FAO. 2018. Perspectives agricoles de l'OCDE et de la FAO 2018-2026. Editions OCDE, Paris. DOI: https://doi.org/10.1787/agr_outlook-2018-fr.

[15] Guyomard H., Manceron S., Peyraud J.-L., 2013. Trade in feed grains, animals, and animal products: Current trends, future prospects, and main issues. *Animal Frontiers* 3(1): 14-18.

1.2. Effects of livestock on the environment and resource use

The consequences of nutrient losses on the quality of surface and ground waters brought attention to the environmental impact of livestock farming in the 1990s. This was followed by concerns about the sector's contribution to global warming[16] and the extent to which production might exceed so-called 'planet boundaries' notably biosphere integrity, land system change, fresh water consumption, nitrogen and phosphorus flow[17].

1.2.1. Livestock impacts on climate

The contribution of livestock to climate change was highlighted in 2006 by the FAO report[16] and is today one of the greatest challenges facing the livestock sector. Livestock contributes to climate change by emitting GHG, either directly (e.g. from enteric fermentation) or indirectly (e.g. from feed-production activities and deforestation). Globally the livestock sector in 2005 was estimated to emit 7.1 Gt of CO_2-eq, which represents 14.5% of all GHG of human origin[18]. More recent evaluation from FAO[19] provides an estimate of 8.1 Gt CO_2-eq in. Methane (CH_4) accounts for about 50 percent of the total followed by nitrous oxide (N_2O) and carbon dioxide (CO_2) that represent almost equal shares with 24 and 26 percent, respectively. Among species bovines are the highest contributors (37.0% beef, 19.8% milk), pigs are the second (10.1%) and then chickens and eggs (9.8%), buffalo (8.6%) and small ruminants (meat and milk of ovines 6.2%). The rest of emissions are allocated to other poultry and non-edible products.

The emissions intensities (EI, the kg of CO_2-eq per unit of output) can vary significantly between and within commodities, reflecting differences in, for example, agro-ecological conditions, and agricultural practices (Figure 6 and 7). It has been argued that this variation provides scope for significant reductions in emissions[18]. These variations are particularly important for bovine meat where EI can vary in a ratio of 1 to 4 in European systems. Comparing global averages, the EI of aquaculture is similar to the main monogastric commodities (pig meat and broiler meat)[20].

[16] FAO: Steinfeld H., Gerber P., Wassenaar T., Castel V., Rosales M., de Haan C. 2006. Livestock's long shadow. FAO, Rome.

[17] Rockstrom J.W., Steffen K., Noone K., Persson A., Chapin F.S., Lambin E.F., Lenton T.M., Scheffer M., Folke C., Schellnhuber H.J. 2009. A safe operating space for humanity. *Nature* 461, 472-475.

[18] FAO: http://www.fao.org/gleam/.

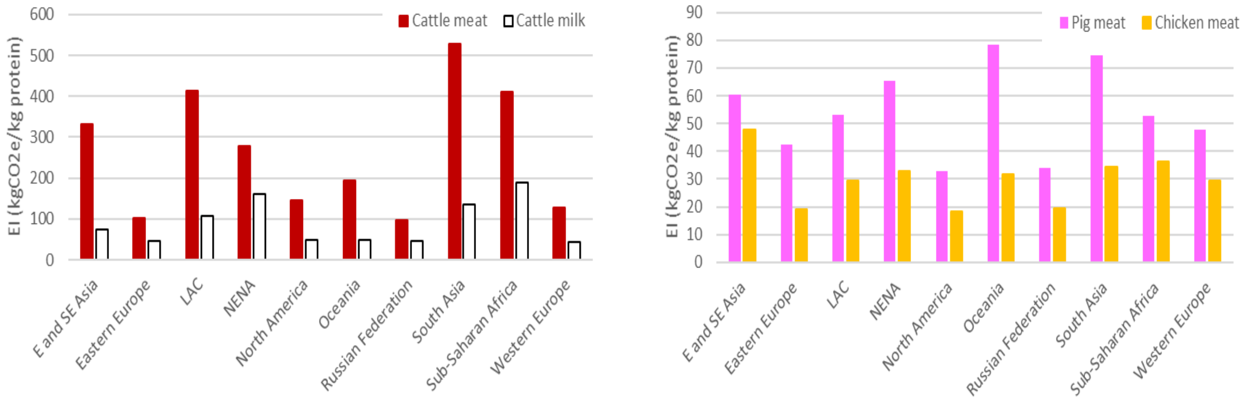
Gerber P.J., Steinfeld H., Henderson B., Mottet A., Opio C., Dijkman J., Falcucci A., Tempio G. 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.

FAO 2019. Five Practical Actions towards Low-Carbon Livestock. Rome.

[19] FAO. 2017. Global Livestock Environmental Assessment Model (GLEAM). Rome, FAO. 109 pp. (available at www.fao.org/gleam/en/).

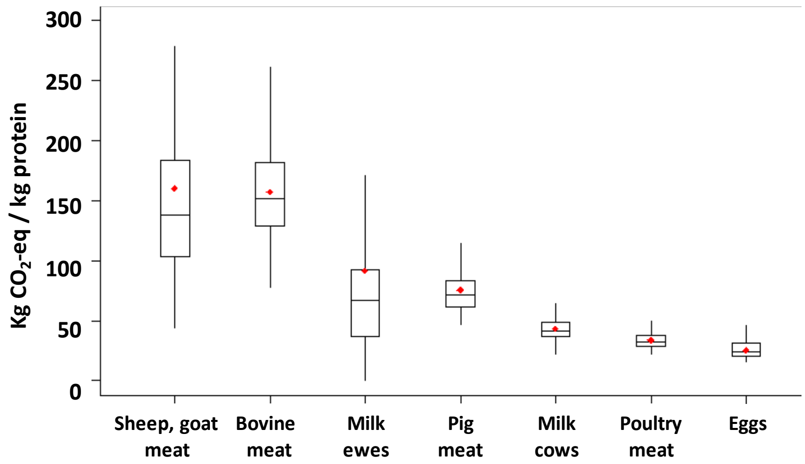
[20] Hilborn R., Banobi J., Hall S.J., Pucylowski T., Walswort T.E., 2018. The environmental cost of animal source foods. *Front Ecol. Environ* 2018; doi:10.1002/fee.1822.

Figure 6: Regional average emissions intensities (EI, the kg of CO_2-eq per unit of output) for 2010 for cattle milk and meat (left) and pig and chicken meat (right) including emissions arising pre-farm and on-farm.



Source: FAO, 2017[19]

Figure 7: Variation in emissions intensities (EI, the kg of CO_2-eq per unit of output) within EU regions (rank NUTS 2). Red dots are the average[21]



Source: Leip et al, 2010[21]

In 2017, the EU-28 agricultural sector generated 10% of the region's total GHG emissions[22], which is less than industry sector (38 %), transport (21%) and residential and tertiary (12 %). However, further emissions arise outside the EU as a result of EU agricultural activity, through the production of inputs such as feed and fertiliser.

- Almost half of the agricultural emissions arising within the EU come from enteric fermentation (mainly ruminants) and the management of manures of (all

[21] Leip A., Weiss F., Wassenaar T., Perez I., Fellmann T., Loudjani P., Tubiello F., Grandgirard D., Monni S., Biala K. 2010. Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS) final report: European Commission, Joint Research Centre, 323 p. http://ec.europa.eu/agriculture/analysis/external/livestock-gas/.

[22] European Environment Agency, 2019. Annual European Union greenhouse gas inventory 1990-2017 and inventory report 2019. Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol, 27 May 2019, EEA/PUBL/2019/051, 962 p.

livestock). Once emissions related to the production, transport and processing of feed are included, the livestock sector is responsible for 81-86%[21] of the agricultural GHG emissions. Gross emission of ruminants can be, at least partly, offsets by soil C sequestration under grassland. The C sequestration potential would range from 0 to 4 t C/ha/year depending on the ecological zone, soil characteristics, climatic conditions and agricultural practices and the level of sequestration (intensity, duration) is still a matter of scientific debate[23].

- The agricultural sector is responsible for 52% of the total EU-CH_4 emissions (mainly livestock and rice cultivation but without counting wetland) and 74 % of total EU-N_2O emission (mainly from fertilizer application and exposed soils). Within the agricultural sector CH_4 represents 55% and N_2O 43% of GHG emissions. These date show that efforts must focus as much on N_2O as on CH_4 for achieving the EU's climate ambition for 2030 and 2050.
- Methane emitted into the atmosphere is removed by photochemical oxidation so that only about half will remain after a decade whereas N_2O and CO_2 remain several decades/centuries[24]. This means that a steady level of methane emissions leads to a steady amount of methane in the atmosphere[25] and do not contribute to the increase of global temperature. Reducing methane emissions would reduce the concentration in the atmosphere, leading to near-term cooling as would be the case with active removal of CO_2. Methane is therefore one of the most powerful levers to slow global warming and any decrease in emission intensity will have very positive effect. It is suggested that to limit warming to 1.5 to 2°C (COP 21), CO_2 and N_2O emissions originated form human activities should be reduced to zero whereas CH_4 emission should be declining but do not have to reach net zero.

Land use change has contributed to EU-28 GHG emissions via their effects on soil carbon stocks. The conversion of arable land into to grasslands or forests contributes to the storage of C in the surface and deep horizons of the soil at a similar rate[26] (0.5 t C/ha/year during the 20 first years), while the conversion of forests and grasslands to arable land leads to rapid losses (Figure 8). Between 1990 and 2017, the net balance was negative at European level[22]. European

[23] Soussana J.F., Tallec T., Blanfort V., 2010. Mitigating the greenhouse gas balance of ruminant production systems through carbon sequestration in grasslands. *Animals* 4, 334-350.

Smith, P., 2014. Do grasslands act as a perpetual sink for carbon? *Global Change Biology*, 20 (9): 2708-2711. DOI: http://dx.doi.org/10.1111/gcb.12561

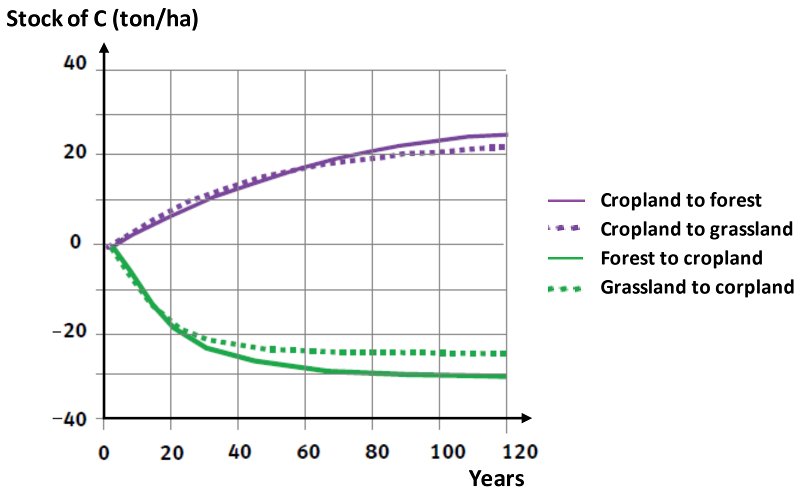
[24] Allen M.R., Shine K.P., Fuglestvedt J.S., Millar R.J., Cain M., Frame D.J., Macey A.H. 2018. A solution to the misrepresentations of CO2-equivalent emissions of short-lived climate pollutants under ambitious mitigation. npj Climate and Atmospheric Science 1:16 ; www.nature.com/npjclimatsci DOI: https://doi.org/10.1038/s41612-018-0026-8

[25] Fuglestvedt J., Rogelj J., Millar R.J., Allen M., Boucher O., Cain M., Forseter P.M., Kriegler E., Shindell D. 2018. Implications of possible interpretations of 'greenhouse gas balance' in the Paris Agreement. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 376(2119), 20160445. DOI: https://doi.org/10.1098/rsta.2016.0445

[26] Arrouays D., Balesdent J.C., Germon P.A. Jayet J.F. Soussana J.F., Stengel P. (eds). 2002. Mitigation of the greenhouse effect - Increasing carbon stocks in French agricultural soils? Scientific Assessment Unit for Expertise. Synthesis of an Assessment Report by the French Institute for Agricultural Research (INRA) on request of the French Ministry for Ecology and Sustainable Development, 32 pp.

Smith P. 2014. Do grasslands act as a perpetual sink for carbon? *Global Change Biology*, *20*(9), 2708-2711. DOI: https://doi.org/10.1111/gcb.12561 agriculture also affects changes in land use outside the EU due to international trade in agricultural products.

Figure 8. Changes in the carbon stock in soils associated with practices causing carbon storage or destocking (uncertainty: +/- 40%)



Source: Fuglestvedt et al, 2018[25]

The sectors are engaged in initiatives to reduce their C footprint. EU-28 agricultural GHG emissions decreased by 24% between 1990 and 2013, from 554 to 423 Mt CO_2-eq[22]. EU agricultural CH_4 decreased by 21%. This is slightly less than the energy sector (29%). The main explanatory factors are the sharp reduction in the number of cattle, especially in Eastern European countries following the fall of the communist regimes. In particular, beef production went down by about 20-25% over this period. Emissions have tended to increase slightly since 2013 under the combined effects of increases in animal number in some countries (Poland, Spain) and N fertilization, increases themselves linked to growth in animal and plant production[27]. At the same time, the decrease in the practice of grazing and its corollaries (converting grasslands, simplification of landscapes) have negative effects on both the environment (reduction of carbon sinks) and biodiversity.

Technical progresses have been achieved and significant progress is still possible to mitigate GHG emissions[28]. Globally mitigation potential can reach 50% in 2050 compared to 2010 using actual technologies but probably less in Europe. Enteric

[27] Eurostat, 2018. Production agricole, indices de prix et revenu agricole. Eurostat, Statistics explained, ISSN 2443-8219: https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=Agricultural_output,_price_indices_and_income/fr&oldid=373156.

[28] Pellerin S., Bamière L., Angers D.A., Béline F., Benoit M., Butault J.P., Chenu C., Colnenne-David C., De Cara S., Delame N., Doreau M., Dupraz P., Faverdin P., Garcia-Launay F., Hassouna M., Hénault C., Jeuffroy M.H., Klumpp K., Metay A., Moran D., Recous S., Samson E., Savini I., Pardon L. 2013. Quelle contribution de l'agriculture française à la réduction des émissions de gaz à effet de serre? Potentiel d'atténuation et coût de dix actions techniques. Synthèse du rapport d'étude, INRA (France), 92 p. http://institut.inra.fr/Missions/Eclairer-les-decisions/Etudes/Toutes-lesactualites/.

Global Research Alliance on Agricultural Greenhouse gases, www.globalresearchalliance.org.

methane is the main source of GHG in ruminant farming, but it is also the most difficult to mitigate. The other sources of emissions are technically easier to master.

- **Changes in feed production** with the use of legumes (forage legumes in grassland, grain legumes) which reduce the use of nitrogen fertilizers and improve feed quality may reduce both N_2O and CH_4 emission to some extent.
- **Smart use of manure** (collection, storage facilities, application) allow to reduce methane emission[29]. Better use of manure to replace synthetic N fertilizer offer additional ways of reducing CH_4, $N_2O$and the CO_2 associated with synthetic fertiliser production. Generating energy via anaerobic fermentation has a strong effect but requires investments.
- **Improved herd management** can reduce emissions. Age at first calving and replacement rate showed potential to reduce enteric CH_4 emissions mainly by modifying the number of dairy cows and replacements heifers in the herd for a given level of milk production on the farm. Reducing age at first calving from 36 to 24 months and replacement rate from 40 to 25% have the potential to reduce emissions by respectively 8 and 10%[30].
- **Improvement of animal health** is a major issue for CH_4 mitigation, notably in developing countries[18] but the importance of this lever is in fact very little known although WHO has quoted that globally, 20% of animal productivity losses would be related to animal diseases.
- **Mitigation of ruminal methane emission** can be achieved by using feed additives. Unsaturated fatty acids (oil seeds), molecules, such as nitro-oxy derivatives (3NOP and methyl 3NOP) can reduce enteric CH_4 emissions up to 30% without negative effects on performance over several lactations[31] However, the presence of residues in milk or meat remains an unresolved issue apart linseed products that increase omega-3 contents in animal product and can thus be considered as a win-win strategy. Plant secondary compounds are the subject of numerous studies but with results that are not always convincing. Selecting low emitting animals is another interesting way on the long term, but some trade-offs might appear, the most efficient animals to digest cellulose being those which also produce the most CH_4 per kg of DM ingested[32].

[29] IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Agriculture, forestry and other land use. Emissions for livestock and manure management, 4, Chap. 10, 87 p.

[30] Dall-Orsolettaa A.C., Leurent-Colette S., Launay F., Ribeiro-Filhoa H.M.N., Delaby L. 2019. A quantitative description of the effect of breed, first calving age and feeding strategy on dairy systems enteric methane emission. Livestock Sci., 224, 87-95. https://doi.org/10.1016/j.livsci.2019.04.015.

[31] Patra A., Park T., Kim M., Yu Z.T. 2017. Rumen methanogens and mitigation of methane emission by anti-methanogenic compounds and substances. *J. Anim. Sci. Biotechn*., 8, 13. https://doi.org/10.1186/s40104-017-0145-9.

[32] Mc Donnell R. P., Hart K.J., Boland T.M., Kelly A.K., Mcgee M., Kenny D.A. 2016. Effect of divergence in phenotypic residual feed intake on methane emissions, ruminal fermentation, and apparent whole-tract digestibility of beef heifers across three contrasting diets. *J. Anim. Sci*. 94:1179–1193.

- **Precision feeding** has also a mitigation effect by increasing feed efficiency using customized balanced feeding programmes for each animal (lower feed intake for similar performance).

Although progress is still possible in Europe, the abatement potential is likely to be relatively low compared to some other regions, where there are more ruminants and higher emissions intensities (Figure 6), which provides greater scope for cost-effective reductions in emissions. While the European cattle population is only 8.9% of world cattle population[33], the EU still has an important role to play in developing and demonstrating mitigation methods and policies that can deployed both domestically and elsewhere in the world.

1.2.2. Local impacts of Livestock on air and water quality

The regional concentration of animal production causes diffuse pollution of air and water. More than 80% of the nitrogen of agricultural origin present in all European aquatic environments is linked to livestock farming activities[34] and livestock farms are the principal emitters of ammonia and account for 90%[35] of ammonia emissions of the agricultural sector when considering emissions linked to the fertilisers used to produce feed. Livestock is responsible for a large share of leaks into coastal waters from rivers, with range of variation according to the zones, from 23 to 47% for nitrogen and from 17 to 26% for phosphorus. The specialization of farms and the regional concentration of animal production generate locally an excess of nutrients, in particular nitrogen and phosphorus (Figure 9), and the consequent pollution of air and water[36]. Public policies such as the Nitrates Directive[37] and the Water Framework Directive have tackled this issue.

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[33] USDA. 2017. World Cattle Inventory. Ranking of countries, 2017. http://beef2live.com/story-world-cattle-inventory-rankingcountries-0-106905. Accessed August 29, 2017.

[34] Westhoek H., Lesschen J.P., Leip A., Rood T., Wagner S., De Marco A., Murphy-Bokern D., Pallière C., Howard C.M., Oenema O., Sutton M.A. 2015. Nitrogen on the table: The influence of food choices on nitrogen emissions and the European environment. European Nitrogen Assessment Special Report on Nitrogen and Food, Centre for Ecology & Hydrology, Edinburgh, UK, 70.

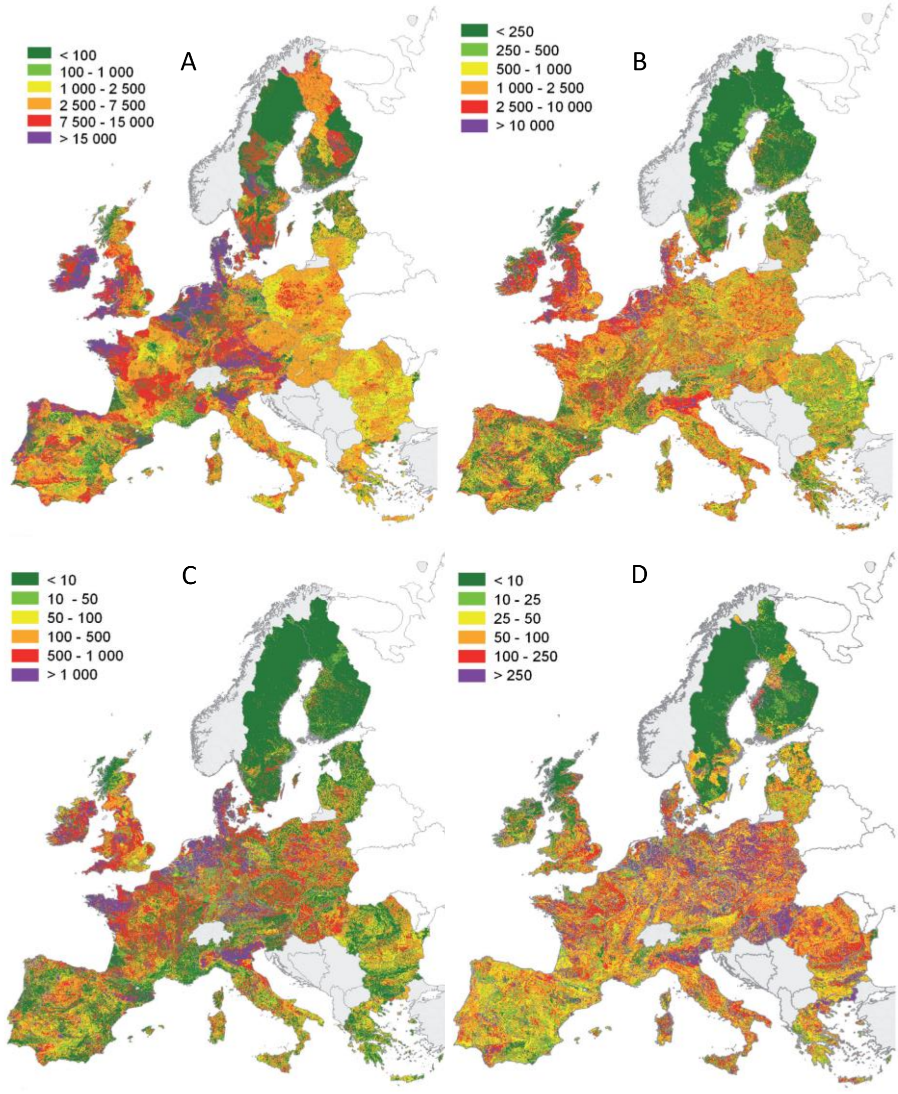
Leip A., Billen G., Garnier J., Grizzetti B., Lassaletta L., Reis S., Simpson D., Sutton M.A., de Vries W., Weiss F., Westhoek H. 2015. Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land use, water eutrophication and biodiversity. Environmental Resource Letters 10, https://doi.org/10.1088/1748-9326/10/11/115004.

[35] European Environment Agency, 2018. Air quality in Europe - 2018 report. EEA, Copenhagen, 88 p.

[36] Leip A., Achermann B., Billen G., Bleeker A., Bouwman A.F., De Vries A., Dragosits U., Doring U., Fernall D., Geupel M., Herolstab J., Johnes P., Le Gall A.C., Monni S., Neveceral R., Orlandini L., Prud'homme M., Reuter H.I., Simpson D., Seufert G., Spranger T., Sutton M.A., Van Aardenne J., Vos M., Winiwarter W. 2011. Integrating nitrogen fluxes at the European scale. *In* : *The European Nitrogen Assessment. Sources, Effects and Policy Perspectives* (M.A. Sutton, C.M. Howard, Erisman J.W., Billen G., Bleeker A., Grennfelt P., Van Grinsven H., Grizzeti B. (eds.), Cambridge University Press, Cambridge, UK, 345-376. The European Commission is not responsible for the use of maps.

[37] Alterra 2011. Recommandation for establishing Action Programmes under directive 91/676/EEC concerning the protection of waters agains pollution by nitrates form agricultural sources. Wageningen: Alterra, (ENV.B.1/ETU/20/10/0063).

Figure 9: Distribution of total nitrogen consumption by livestock (A) in Europe and reactive nitrogen emissions to aquatic systems as Nitrate (B) and air as Ammonia (C) and N_2O (D) (in kg N / km2 / year).



Source: USDA, 2017[33]

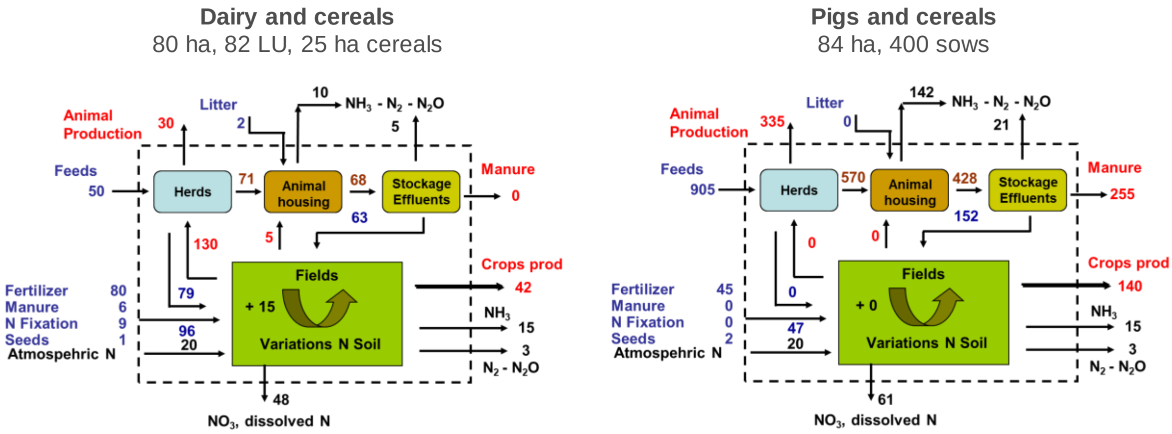
However, the same nitrogen pressure can result in different environmental impacts depending on the sensitivity of the local environment and its capacity to use or transform nitrogen from animal waste (Carrying capacities of territories)[38]. The nitrate content in water does not depend solely on the level of nitrogen balance surpluses, but also on climate, soil, and land use (animal per ha, proportion of cropland, etc.). In particular, a large proportion of pastures in a given area reduces risks for nitrate leaching, ammonia emissions and P runoff. In addition, other sources of variation that are rarely quantified may play a role in the environmental

[38] Sutton M.A., Howard C.M., Erisman J.W., Bealey J., Billen G., Bleeker A., Bouwman L., Grennfelt P., van Grinsven H., Grizzetti B. 2011. The challenge to integrate nitrogen science and policies: the European Nitrogen Assessment approach. In: Sutton et al., eds. The European Nitrogen Assessment. Sources, Effects and Policy Perspectives. Cambridge: Cambridge University Press, 52-96.

impacts of nitrogen excesses: soil N organization, other gaseous losses, inhibition of nitrification and residence time in aquifers.

Efficiency at the scale of the animal is not representative of that of the production system. Efficiency of N use is low when calculated at the animal level: 45% of feed N is retained by chicken, 35% by pig, 20 to 30% by dairy cow and 20% to 10% by beef cattle. The major part of feed nitrogen is excreted into the environment. At the livestock farm scale, the efficiency of nitrogen inputs increases because of recycling animal manure and production of crops[39]. At this scale animal density per hectare, manure utilization and associated use of land has determining roles on nitrogen (and also P) losses. N efficiency at the farm gate results from complex interactions (Figure 10), one improvement can be cancelled by bad management at a previous or subsequent stage.

Figure 10: N flow in mixed farming systems with dairy and pigs



	Animal	Farm gate
Inputs	180	148
Outputs	30	72
Balance	150	76
N efficiency	0.16	0.49

	Animal	Farm gate
Inputs	905	952
Outputs	335	475
Balance	570	477
N efficiency	0.37	0.50

Source: adapted from EEA, 2018 and Leip et al, 2011[35, 36]

Options are available to improve N and P efficiency at animal, farm and territory level[40]. Much progress has been achieved by reducing protein supply

[39] Jarvis S., Hutchings N., Brentrup F., Olesen J.E., van de Hoek K.W. 2011. Nitrogen flows in farming systems across Europe. In: Sutton M.A., Howard C.M., Erisman J.W., Billen G., Bleeker A., Grennfelt P., van Grinsven H., Grizzetti B. (eds). The European Nitrogen Assessment. Sources, Effects and Policy Perspectives. Cambridge: Cambridge University Press, 211-228.

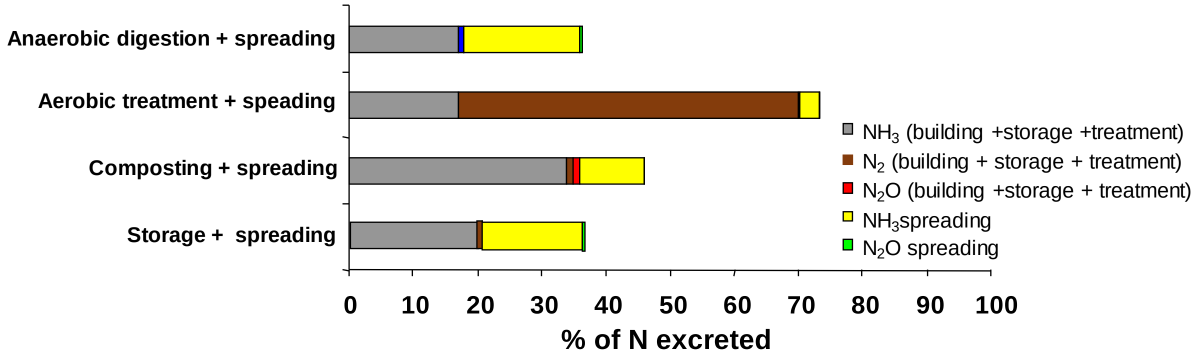
[40] Peyraud J.L., Cellier P., Dupraz P., Aarts F. 2014. Options for the better use of less nitrogen on livestock farms. Advance in Animal Biosciences 5, special issue 1, 55-58.

Peyraud J.L., Cellier P., Aarts F., Béline F., Bockstaller C., Bourblanc M., Delaby L., Dourmad J.Y., Dupraz P., Durand P., Faverdin P., Fiorelli J.L., Gaigné C., Kuikman P., Langlais A., Le Goffe P., Lescoat P., Morvan T., Nicourt C., Parnaudeau V., Rochette P., Vertes F., Veysset P., Rechauchere, O., Donnars, C. 2014. Nitrogen flows and livestock farming: lessons and perspectives. *Advance in Animal Biosciences* 5, special issue 1, 59-69.

Webb J., Pain B., Bittman S., Morgan J. 2010. The impacts of manure application methods on emissions of ammonia, nitrous oxide and on crop response-A review. *Agri. Ecosystems, Environ* 137 (1-2), 39-46.

and using synthetic amino acids to better match the ration to the animal requirements. This is the case of the multiphase feeding strategies for pigs with a 30-40% reduction in N output for similar growth rate since 1990. Precision feeding might allow a further 20% reduction[41]. A major path for preserving nitrogen and reducing purchases of synthetic N fertilizer is the control of the entire manure management chain (Figure 11) as losses vary from 30 to 75% of nitrogen excreted by animals at this stage[40] Technical measures and innovations are now available to limit emissions, in particular ammonia inside livestock housing, during storage and manure application to land. Technological treatment of manure creates possibilities for better management of nitrogen balances by producing standardised and marketable fertilisers (N and P) or composts that can be easily exported to other places, especially in cereal specialized areas. Recent evaluations of the nitrate directive by the French Ministry of Agriculture and the Ministry of Environment show that the nitrate contents of surface and groundwater have significantly decreased in Brittany, a region with high density livestock, whereas the nitrate content of groundwater continues to increase in specialized crop areas even beyond the limit of 50 mg / L.

Figure 11: Effect of pig manure management on N emissions



Source: adapted from Jarvis et al, 2011[39]

1.2.3. Ambivalent effects of livestock on biodiversity and soil quality

The impacts of human activities on global biodiversity is huge[42], particularly those of food production (Figure 12)[43]. Livestock has a role, which can be positive or negative through local and global levels including agricultural land use and land use change mobilized locally or remotely for animal feeding and management of manures. However the specific contribution of livestock is difficult to quantify because the effect on soil fertility and biodiversity are due to changes at work in the whole of the agricultural sector. LEAP is trying to tackle this challenge by

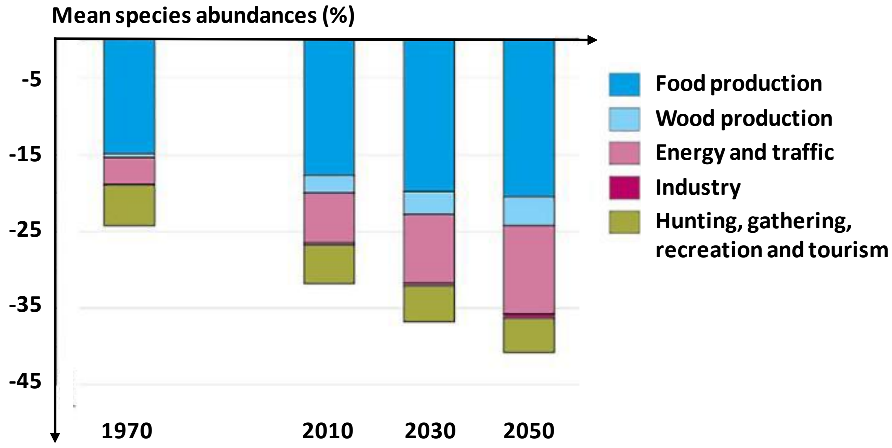
[41] H2020 Feed a gene project, J Van Milgen, coordinator.

[42] Gaston K.J., Blackburn T.M., Goldewojk K., 2003. Habitat conversion and global avian biodiversity loss. *Proc. Biol. Sci.*, 270, 1293-1300. https://doi.org/10.1098/rspb.2002-2303.

[43] Kok M., Alkemade R., Bakkenes M., Boelee E., Christensen V., Van Eerdt M., van der Esch S., Janse J., Karlsson-Vinkhuyzen S., Kram T. 2014. How Sectors Can Contribute to Sustainable. Use and Conservation of Biodiversity. 79. PBL.

providing quantitative guidelines for measuring the positive and negative aspects of livestock impacts on biodiversity.

Figure 12: Impact on biodiversity of different production sectors under a trend scenario[40]



Source: Jarvis et al, 2011[39]

The role of European livestock on deforestation is hotly debated because deforestation is a major cause of biodiversity decline, is responsible for neatly 12% of GHG emissions[44] (the second biggest cause of climate change after burning fossil fuels) and impacts the livelihoods of 25% of the world's population[45]. A typical example is the impact of soy cultivation in Brazil[46]. The dependence of European livestock on American soy dates from the creation of the Common Agricultural Policy, with the free access of American soy in return for the protection of our cereal market. Since the Blair House agreements (1992), the EU must limit its production for oilseed and protein crops. European livestock sector had to import soybeans first from the USA, then from Brazil and from Argentina.

- Over the period 1990-2008, the EU imported almost 36% of all deforestation embodied in crop and livestock products traded between regions[47] (239 million hectares) while 33% of deforestation embodied in crops and 8% of deforestation embodied in livestock products were traded internationally. A

[44] Smith P et al. 2014. Agriculture, Forestry and Other Land Use (AFOLU). In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer O et al (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA.

[45] FAO. 2018. The State of the World's Forests 2018 - Forest pathways to sustainable development. Rome. http://www.fao.org/3/a-i9535en.pdf.

[46] Fearnside P.M., 2001. Soybean cultivation as a threat to the environment in Brazil. Environmental Conservation, 28 (1): 23-38.

Gibbs H.K., Rausch L., Munger J., Schelly I., Morton D.C., Noojipady P., Soares-Filho B., Barreto P., Micol L., Walker N.F. 2015. Brazil's Soy Moratorium. Science, 347 (6220): 377-378. http://dx.doi.org/10.1126/science.aaa0181.

[47] European Commission, 2013. The impact of EU consumption on deforestation: Comprehensive analysis of the impact of EU consumption on deforestation. Study funded by the European Commission, DG ENV, and undertaken by VITO, IIASA, HIVA and IUCN NL, 348 p.

more recent evaluation shows that when looking at deforestation embodied in total final consumption (palm oil, soy, meat, cocoa, maize, timber, rubber), the EU27 is consuming 732 kha (2004) or 10% of the global embodied deforestation consumption (7,290 kha per year)[48]. Deforestation embodied in EU27 consumption is almost entirely due to imports, as deforestation within the EU is negligible. Africa and South and Central America are the largest consumers of deforestation (30% of the global share each), this deforestation being associated with commodities and products that are produced locally.

- In line with the EU ambition to identify and promote deforestation free commodities, the European soy imports are decreasing. The EU's consumption of protein-rich products for livestock in 2016-17 amounted to 26.6 Mt of crude protein; of this 17Mt were imported, including 13 Mt of protein from soybeans, equivalent to an area of 15 million ha. Beyond reducing quantities, supply-chains are also increasingly concerned about the origin of soy and are seeking soy not linked to deforestation. In 2018-19, FEFAC[49] estimated that 22% of imported soya used in animal feed had a high risk of coming from deforestation and 78% came from regions with a low risk of deforestation (the data are 10- and 90 respectively when including European soybean production).

Livestock, especially ruminants, can have a positive impact on biodiversity and soil carbon via the maintenance of permanent grassland and hedges and optimized use of manure. These effects are recognized at European scale. Permanent grassland area is protected by EU and national legislations and livestock seems to be concomitant with most of the High Natural Value agricultural areas, notably in grassland based ruminant systems even if certain pig farms, horse and buffalo farms may have local importance. Mixed systems are also widely represented[50].

- Important ecosystems services provided by grasslands have been identified and described[51] and the value of grasslands thus clearly extends far beyond their direct economic value for animal production systems[52]. Concerning biodiversity, about 50% of the endemic plant species of Europe are dependent on the grassland biotope, 50% of bird species depend on grassland habitats for food and reproduction[53] and vegetation also constitutes habitats for arthropod

[48] European Commission 2019. Stepping up EU Action to Protect and Restore the World's Forests. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, 22 p

[49] European Feed Manufacturers' Federation, https://www.fefac.eu/.

[50] IEEP, Alterra, Tucker G., Braat L. 2010. Reflecting environmental land use needs into EU policy: Preserving and enhancing the environmental benefits of" Land services": Soil sealing, biodiversity corridors, intensification/marginalisation of land use and permanent grassland. Final report to the European Commission, DG Environment on Contract ENV.B.1/ETU/2008/0030. Wageningen: Institute for European Environmental Policy; Alterra, 395 p. http://library.wur.nl/WebQuery/wurpubs/fulltext/160020.

[51] MEA. 2005 Ecosystems and Human Well-being: Current State and Trends, Volume 1. 901 p.
Huguenin-Elie O., Delaby L., Klumpp K., Lemauviel-Lavenant S., Ryschawy J. 2018. The role of grasslands in biogeochemical cycles and biodiversity conservation. In Improving grassland and pasture management in temperate agriculture. Edts Marshall A., Collins R. IBERS Abesystwyth University, UK.

[52] National Research Council (2005). *Valuing Ecosystem Service: Towards Better Environmental Decision making*. National Academies Press, Washington, DC.

[53] Veen P., Jefferson R., de Smidt J., van der Straaten J. 2009. Grassland in Europe of high nature value. KNNV Publishing, Zeist (Netherlands), 320 p.

populations[54]. Soil under permanent grassland is characterized by a high level of C and a high biodiversity of invertebrates[55]. The role of grassland and associated livestock goes beyond this because the specific richness (gamma) of a heterogeneously managed landscape exceeds the specific richness (alpha) of the plot. In intensive cereal systems, grasslands grazed by ruminants have a critical role in shaping the distribution and abundance of organisms of different trophic levels, including plants, grass hoppers, small mammals and birds[56]. Differentiated grassland management at landscape level leads to temporal heterogeneity, allowing mobile animal species to alternatively find shelter and food resources in the different types of grassland habitats[57].In mixed farming systems, temporary grassland increases the richness and diversity of habitat and therefore positively influences biodiversity at the territorial level[58], notably for bees, arthropods and birds. In mountain grasslands are often characterized by greater plant and animal biodiversity than the wooded and shrubby formations of these same landscapes[59] and grazing allows the control of shrub cover[60].

- Livestock also has effects via hedges and the maintenance of hedgerow landscapes (habitats for some taxa, role of ecological corridor) associated with grassland.
- The contribution of livestock manure with a high C / N ratios (compost, manure) has a generally favorable impact on soil organic matter content and macrofauna (earthworms). Regular supply of effluent appears to improve soil biological functions [61] and to have an effect on soil microbial biodiversity because they

[54] Dumont B., Farruggia A., Garel J.P., Bachelard P., Boitier E., Frain M. 2009. How does grazing intensity influence the diversity of plants and insects in a species-rich upland grassland on basalt soils? *Grass Forage Sci*., 64(1), 92–105.

[55] European Soil Data Center, http://eusoils.jrc.ec.europa.eu/esdb_archive/octop/octop_download.html European Commission – Joint Research Centre, Institute for Environment and Sustainability).

Soussana J., Duru M. 2007. Grassland science in Europe facing new challenges: biodiversity and global environmental change. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natura Resources, 272: 1-11.

[56] Bretagnolle V., Gauffre B., Meiss H., Badenhauser I. 2012. The role of grassland areas within arable cropping systems for the conservation of biodiversity at the regional level. In Grassland productivity and ecosystem services. In Lemaire G., Hodgson H., Chabbi A. (Edts), CAB International, 251-260.

[57] Sabatier R., Doyen L., Tichit M. 2014. Heterogeneity and the trade-off between ecological and productive functions of agro-landscapes: A model of cattle-bird interactions in a grassland agroecosystem. *Agric. Syst*., 126, 38–49.

[58] Burel F., Aviron S., Baudry J., Le Féon V., Vasseur C. 2013. The structure and dynamics of agricultural landscapes as drivers of biodiversity. In: Fu, B.; Jones, B.K.E., eds. Landscape ecology for sustainable environment and culture. Springer, 285-308.

[59] Koch B., Edwards P.J., Blanckenhorn W.U., Buholzer S., Walter T., Wuest R.O., Hofer G. 2013. Vascular plants as surrogates of butterfly and grasshopper diversity on two Swiss subalpine summer pastures. Biodiversity and Conservation, 22 (6-7): 1451-1465. DOI: http://dx.doi.org/10.1007/s10531-013-0485-5.

[60] Agreil C., Magda D., Meuret M., Hazard L., Osty P.L. 2010. When sheep and shrub make peace on rangelands: linking the dynamics of ruminant feeding behavior and dominant shrub responses on rangeland. Hauppauge: Nova Science Publishers, Inc (Horizons in Earth Science Research, Vol 1), 383-401.

[61] Cotton D.C.F., Curry J.P. 1980. The effects of cattle and pig slurry fertilizers on earthworms (oligochaeta, lumbricidae) in grassland managed for silage production. *Pedobiologia*, 20 (3): 181-188.

Diacono M., Montemurro F. 2010. Long-term effects of organic amendments on soil fertility. A review. *Agro. Sustainable Develop.,* 30 (2): 401-422. DOI: http://dx.doi.org/10.1051/agro/200904.

are both a source of many nutrients for native soil flora and they are also complex inoculum[62].

These positive effects are modulated by practices. In general, intensification of grassland management negatively affect C sequestration and the specific floral richness and associated animal biodiversity (insects) in grassland decreases with the increase in the intensity of their use[63]. At the landscape level, the conversion of permanent grassland to arable land remains the first factor explaining the decrease in the carbon content of soils and biodiversity losses in Europe[64]. Drug treatment residues in manures contribute to affect the soil fauna and can be transferred to water and could contribute to the dissemination of antimicrobial resistance[65]. However there is still very little information and much uncertainty about the soil fate of antibiotic resistance genes carried in manure[66] and the potential human health risk. Finally, liquid manures do not have the same soil benefits as solid manure and over-application leads to soil P accumulation and eutrophication[67].

1.2.4. Do livestock use resources inefficiently?

The contribution of livestock to food security is a more complex matter than often claimed. A recurring idea is that animal use resources inefficiently, notably ruminants. It is true that animals are secondary or even tertiary processors of plants that use solar energy to produce calories and that the addition of a trophic level always leads to a loss of energy efficiency. However livestock also enable inedible biomass to be integrated into the food chain and we need to carefully consider the direct competition between uses of plant resources and the indirect competition through the land devoted to the production of feed.

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[62] Bittman S., Forge T.A., Kowalenko C.G. 2005. Responses of the bacterial and fungal biomass in a grassland soil to multi-year applications of dairy manure slurry and fertilizer. *Soil Biology Biochem.,* 37 (4), 613-623.

Lalande R., Gagnon B., Simard R.R., Cote D., 2000. Soil microbial biomass and enzyme activity following liquid hog manure application in a long-term field trial. *Can. J. Soil Science* 80 (2), 263-269.

[63] Sabatier R., Durant D., Hazard L., Lauvie A., Lecrivain E., Magda D., Martel G., Roche B., de Sainte Marie C., Teillard F., Tichit M. 2015. Towards biodiversity-based livestock farming systems: review of evidence and options for improvement. CAB Reviews, 10 (20): 1-13. DOI: http://dx.doi.org/10.1079/PAVSNNR201510025.

Soussana JF., Lemaire G. 2014. Coupling carbon and nitrogen cycles for environmentally sustainable intensification of grasslands and crop-livestock systems. *Agr. Ecosyst. Environ*., 190, 9–17.

[64] Lal R. 2004. Soil carbon sequestration to mitigate climate change. *Geoderma*, 123 (1-2): 1-22. DOI: http://dx.doi.org/10.1016/j.geoderma.2004.01.032.

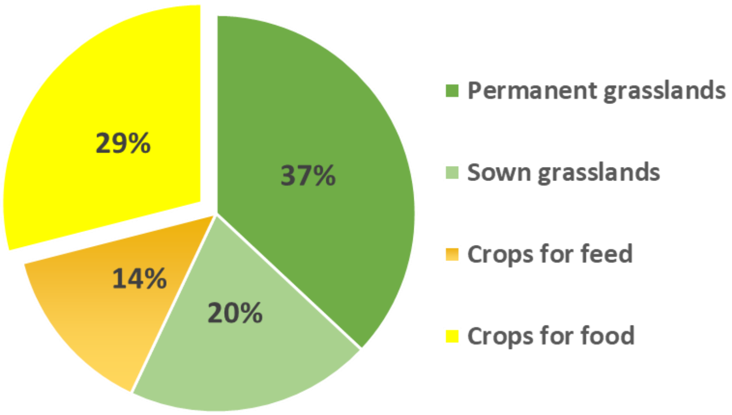
[65] Finley R.L., Collignon P., Larsson D.G.J., McEwen S.A., Li X.Z., Gaze W.H., Reid-Smith R., Timinouni M., Graham D.W., Topp E. 2013. The Scourge of Antibiotic Resistance: The Important Role of the Environment. *Clinical Infectious Diseases*, 57 (5): 704-710.

[66] Ashbolt N.J., Amezquita A., Backhaus T., Borriello P., Brandt K.K., Collignon P., Coors A., Finley R., Gaze W.H., Heberer T., Lawrence J.R., Larsson D.G.J., McEwen S.A., Ryan J.J., Schonfeld J., Silley P., Snape J.R., Van den Eede C., Topp E. 2013. Human Health Risk Assessment (HHRA) for Environmental Development and Transfer of Antibiotic.

[67] Houot S., Pons M.N., Pradel M., Aubry C., Augusto L., Barbier R., Benoit P., Brugère H., Casellas M., Chatelet A., Dabert P., Doussan I., Etrillard C., Fuchs J., Genermont S., Giamberini L., Helias A., Jardé E., Lupton S., Marron N., Menasseri S., Mollier A., Morel C., Mougin C., Parnaudeau V., Pourcher A.M., Rychen G., Smolders E., Topp E., Vieublé L., Viguie C., Tibi A., Caillaud M.A., Girard F., Savini I., De Marechal, S., Le Perchec S. 2014. Valorisation des matières fertilisantes d'origine résiduaire sur les sols à usage agricole ou forestier.Impacts agronomiques, environnementaux, socio-économiques. Paris: Inra, 103 p. https://www6.paris.inra.fr/depe/Media/Fichier/Expertises/Mafor/synthese-janv-2015.

- **A significant part of the area used to feed livestock is marginal land or grasslands providing ecosystems services.** Globally, livestock use 70% (2.5 billion ha) of agricultural land[68], but half of this area is permanent grassland and marginal land that cannot be readily cultivated[69] and are used exclusively by ruminants. Ruminants grazing in these areas therefore directly contribute to food security by providing milk and meat from non-edible biomasses. The other half consists of 0.7 billion ha of temporary grassland that could certainly be cultivated but this will lead to the loss of ecosystem services they provided. At last, livestock farming globally uses 0.7 billion ha of arable land and from this point of view, directly competes with human food. In Europe, livestock uses 66 million ha of permanent grassland (40% of the European agricultural area) and up to 60% of arable land.

Figure 13: Land use by livestock farming (% of global agricultural area)



Source: Mottet et al 2017[69], *based* on FAO Stat 2016

- **In OECD countries, the area of land (in m²) used to produce 1 kg of protein** varies from 47 to 64 for pork, from 42 to 52 for chicken, from 33 to 59 for milk, from 35 to 48 for eggs and from 144 to 258 for beef[70]. The production of pork or poultry in an organic system requires twice as much area as conventional production. For comparison, it takes 7 to 15 m² to produce 1 kg of grain protein according to crop yield and protein content. About 80% of the crops fed to EU livestock are grown within the EU. The cereals and forages used as feed are overwhelmingly of domestic origin (EC 2020)[71]. In 2017-18 roughage (grass and maize silage) represented 46% and cereal crops 22% of EU total feed protein use (Figure 14). Oilseed meals supplied almost a quarter of the feed proteins, with the EU producing only 26% of what it consumes for meals from soya bean and rapeseed (EC, 2020) despite a recent but still very

[68] Foley J.A., Ramankutty N., Brauman K.A., Cassidy E.S., Gerber J.S., Johnston M., Mueller N.D., O'Connell C., Ray D.K., West P.C., Balzer C., Bennett E.M., Carpenter S.R., Hill J., Monfreda C., Polasky S., Rockstrom J., Sheehan J., Siebert S., Tilman D., Zaks D.P.M. 2011. Solutions for a cultivated planet. *Nature* 478, 337–342.

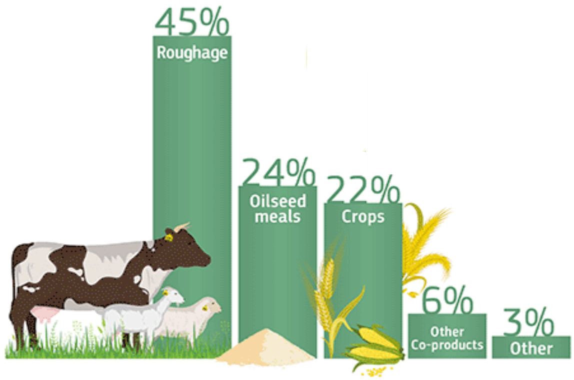
[69] Mottet A., de Haan C., Falcucci A., Tempio G., Opio C., Gerber P. 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security*, 14, 1-18.

[70] de Vries M., de Boer I.J.M. 2010. Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livestock Sci.* 128, 1–11.

[71] EC 2020. https://ec.europa.eu/info/news/commission-publishes-overview-eu-feed-supply-2019-may-20_en.

partial substitution of soya imports by domestic rapeseed cake and, to a lesser extent, sunflower cake, co-products of the processing of these oilseeds into biodiesel.

Figure 14: Share of protein sources in animal feed (green values) and proportion of feed use of EU origin (black values) in 2017-18



Source: European Commission, 2020[71]

- **Livestock recycle biomass/protein that is not directly usable for human food to produce food of high nutritional quality.** If it takes an average of 6 kg of plant protein (from 2 to 10 depending on the species and farming systems) to make 1 kg of animal protein[72] we also need to consider that 86% of protein used by livestock are not edible as human food[70]. Globally livestock use 6 billion tonnes dry matter, grazed biomass ("grassland and leaves") occupies about 50% of the global feed intakes, the other feed categories are crop residues (19%), by products (10%), fodder crops (8%) and primary crops ("grains"; 13%)[70]. Using this metric it appears that contrary to a popular belief, livestock farming is more efficient than often claimed and that ruminants, notably dairy cows, are even more efficient than non-ruminants because they use primarily cellulose. In Europe, several studies concluded that grassland based ruminants are net protein producers[73], they produce more protein in milk and meat that they consume (as human) edible protein sources. We need to carefully consider the direct competition between uses of plant resources and the indirect competition through the land devoted to the production of feed.

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[72] Pimentel D., Pimentel M., 2003. Sustainability of meat –based and plant based diets and the environment. *Am. J. Cli. Nutr*. 78, 660S-663S.

[73] Ertl P., Klocker H., Hörtenhuber S., Knaus W., Zollitsch W., 2015. The net contribution of dairy production to human food supply: the case of Austrian dairy farms. *Agric. Systems*, 137, 119-125.

Wilkinson J. M. 2011. Re-defining efficiency of feed use by livestock. *Animal*, 5, 1014-1022.

Laisse S., Baumont R., Dusart L., Gaudré D., Rouillé B., Benoit M., Veysset P., Rémond D., Peyraud J.L. 2019. L'efficience nette de conversion des aliments par les animaux d'élevage : une nouvelle approche pour évaluer la contribution de l'élevage à l'alimentation humaine. *INRA Prod. Anim., 31* (3), 269-288. https://prodinra.inra.fr/record/458284.

Table 1: Feed and protein of plant origin required to produce 1 kg of protein of animal food

	Ruminants	Non-ruminants
Total feed intake	133	30
Human edible food of plant origin required	5.9	15.8
Human edible protein of plant origin required	0.6	2.0

Source: Mottet et al 2017[69]

- **Coupling livestock and plants production to increase the edible protein production per hectare.** Today livestock use a (too) large amount of cereal, however excluding livestock would deprive us of their abilities to value marginal land area not suitable for crop production, and to add-value to plant by-products and other biomass streams such as crop residues. Several scenario show that area required to feed a population is minimal for a diet containing 10-20 g of protein from animal origin and increase for a vegan population as livestock is not used to recycle marginal land and by-products into the food chain and it also increase rapidly for diet with high proportion of protein of animal origin[74]
- **Water consumption is also a matter of debate**. The water consumed by farm animals can be divided into fresh surface and underground water ("blue water") and soil water ("green water") which does not runoff or recharge an aquifer and largely (95%) returns to the atmosphere as vapour (evapo-transpiration). Therefore despite that globally, 90% of the water consumed by livestock is green water[75], it makes sense to focus on reducing blue water consumption because livestock consume 8 to 15% of water resource worldwide (FAO)[16-18]. According to the ISO standard[76] which focuses on blue water, the ranges of estimates vary between systems from 50 to 520 L/kg of beef, 50 to 200 L/kg pig meat, 0.10 to 36 L/kg of sheep meat, and 0.01 to 461 L/litre of milk. This consumption of blue water needs also to be put into perspective with the availability of local water expressed by the water stress index at a watershed level[77]. Meat production (and irrigation) is a major competitor with other uses of water, including that required to maintain natural ecosystems and

[74] van Zanten H.H.E., Meerburg B.G., Bikker P., Herrero M., de Boer I.L.M., 2015. Opinion paper: The role of livestock in a sustainable diet:a land-use perspective. *Animal*, page 1-3. DOI: https://doi.org/10.1017/S1751731115002694.

Schader C., Muller A., El-Hage Scialabba N., Hecht J., Isensee A., Erb K.H., Smith P., Makkar H.P.S., Klocke P., Leiber F., Schwegler P., Stolze M., Niggli U. 2015. Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. *J. R. Soc. Interface* 12: 20150891.

Röös E., Patel M., Spangberg J., Carlsson G., Rydhmer L., 2016. Limiting livestock production to pasture and by-products ina search for sustainable diets. *Food Policy*, 1-16.

[75] Ran, Y., Lannerstad, M., Herrero, M., Van Middelaar, C.E., De Boer, I.J.M. 2016. Assessing water resource use in livestock production: A review of methods. *Livestock Science*, 187: 68-79. DOI: http://dx.doi.org/10.1016/j.livsci.2016.02.012.

Mekonnen M.M, Hoekstra A.J. 2012. 'A Global Assessment of the Water Footprint of Farm Animal 1033 Products'. *Ecosystems* 15 (3): 401–15. DOI : https://doi.org/10.1007/s10021-011-9517-8.

[76] ISO, 2015. Management environnemental -- Empreinte eau -- Principes, exigences et lignes directrices.

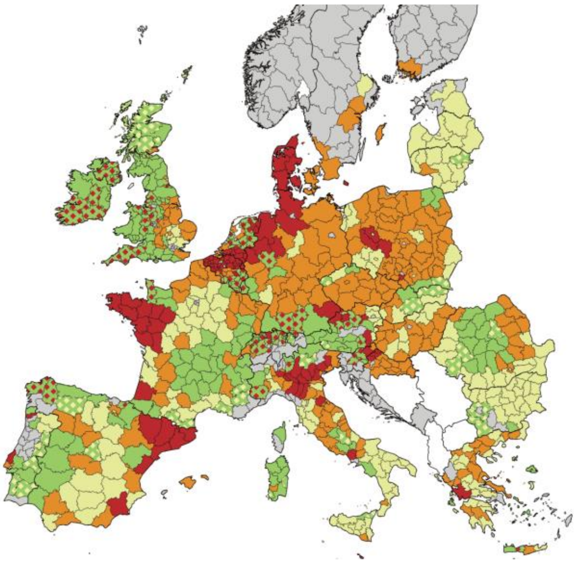
[77] Pfister S., Koehler A., Hellweg S., 2009. Assessing the environmental impacts of freshwater consumption in LCA. *Environ. Sci. Technol.* 43, 4098e4104.

human needs, in water-stressed areas (including southern European countries).

1.3. A diversity of livestock farming systems providing a diversity of services and disservices

Many of the contributions of livestock farming depend on the farming systems implemented and the territories in which they operate. It is not possible to consider livestock as a whole and there is no "one size fit all" solution. A comprehensive study has proposed a typology to describe the diversity of European livestock farming systems, based on two criteria: the share of permanent grassland in the useful agricultural area (UAA) and the animal density expressed in Unit of Livestock per hectare of UAA[78]. Six types of farming systems have been defined and the diversity of services (positive or negative) provided for five domains (markets, environment, use of inputs, rural vitality and social-cultural issues) in each of them have been highlighted (Figure 15).

Figure 15: Typology and localisation of European livestock systems



	Agricultural area million ha	Agricultural area % total	Livestock population million LU	Livestock population % total	Stocking rate (LU/ha)
	18.9	**10.5**	**40.8**	**29.5**	**2.15**
	12.0	**6.7**	**20.1**	**14.6**	**1.70**
	34.7	**19.3**	**25.6**	**18.5**	**0.75**
	12.2	**6.8**	**2.9**	**2.1**	**0.25**
	56.8	**31.6**	**36.8**	**26.6**	**1.20**
	44.9	**25.0**	**11.9**	**8.6**	**0.30**

Source: ***adapted from Dumont et al, 2016[7] and Hercule et al, 2018[78]***

In areas with intensive farming and little grassland local environmental impacts are a huge challenge. They are characterized by high production per unit of area and per unit of work, at relatively low costs, with significant use of inputs, mainly for animal feed purchased outside the territory. Negative environmental impacts on water, air, soil and biodiversity are prevailing. The spatial concentration of production amplifies the impacts of nitrogen pollution:

[78] Hercule J., Chatellier V., Piet L., Dumont B., Benoit M., Delaby L., Donnars S., Savini I., Dupraz P. 2018. Une typologie pour représenter la diversité des territoires d'élevage en Europe. *INRA Prod. Anim.* 30 : 285-302.

Dumont B., Ryschawy J., Duru M., Benoit M., Chatellier V., Delaby L., Donnars C., Dupraz P., Lemauviel-Lavenant S., Méda B., Vollet D., Sabatier R., 2019. Review: Association among goods, impacts and ecosystem services provided by livestock farming. *Animal*. 13, 1773-1784.

eutrophication and acidification still constitute an important limit despite significant progress. Conversely the emission of GHG are often low per unit of product. Improvement of animal welfare is also a huge issue notably for the intensive farming systems.

In areas with intensive grassland based systems, the eutrophication is low and GHG emissions per unit of product is relatively low. The important place of grazing makes it possible to obtain very low production costs and high production per unit of area and per unit of work. This is typically the case of Ireland. Biodiversity (flora, insects and birds) is relatively low because grassland are dominated by highly fertilized perennial ryegrass and the proportion of habitat is low. It is important to preserve the remaining landscape infrastructures and the landscape mosaic.

In marginal zones maintaining livestock farming is a challenge for the conservation of many heritage ecosystems of high ecological value. Marginal zones includes territories specialized in extensive ruminant farming systems based on permanent grassland (humid mountains zones) and transhumant systems in Mediterranean zones. The environmental benefits are numerous including soil (carbon storage, no erosion), water purification and preservation of biodiversity (including avifauna), maintenance of open landscapes and natural habitat, regulation of flood (marshes) and preservation against fire in dry zone. Maintaining livestock farming which is subject to strong natural constraints requires an appropriate agro-environmental policy. The dynamics of the territories, through the promotion of quality products, also appear to be a lever to preserve livestock activities.

Livestock farming in urban and peri-urban areas is finding a marked revival of interest in the EU due to the growing interest of consumers for 'local product" and for "nature" and the desire to create social ties. The main obstacles of reintroduction of livestock into the city are linked to nuisances and epidemiological risks. In peri-urban areas, the reintroduction of livestock is boosted by the development of direct sales and the supply of various services including leisure (e.g. horses). Herbivore farming maintains grasslands that provide different regulatory services and meet the expectations of city dwellers for recreational spaces in close proximity to cities. The development of animal husbandry is mainly constrained by the strong land pressure which is exerted on these spaces.

1.4. Animal welfare

The importance of the welfare of farm animals has been gradually affirmed over the last 50 years and citizens' interest in living and dying animals continue to increase. Today a very large majority of European citizens (94%) attach importance to animal welfare and 82% of them consider that farm animals should be better protected[79]. Europe took up animal welfare issues in 1976

[79] European Commission, 2016.

with the Council of Europe convention for the protection of farm animals and can today be considered as the most advanced region. Welfare issue has also been gradually taken into account by the livestock sector including distribution[80], as evidenced by the recent movement of rejection of eggs produced by caged hens. However welfare remains a big issue:

- The specialization and intensification of livestock farming systems has had implications causing stress and pain with artificial living conditions in industrial type buildings, damage of animal integrity (dehorning, live castration, declawing and cutting of the beak, cutting of tail, crushing of chicks, etc.), separation from familiar partners and mixing with other. Other indirect consequences are reduced lifespan of reproductive female (e.g. dairy cows, hens) and the "economic non-value" of some young males which are slaughtered immediately after their birth (e.g. crushing of the chicks). Extensive farming systems have also some weak points: increased risk of parasitism and contact with pathogens and wild fauna which can go as far as predation (attacks by foxes or wolves) and existence of buildings, often old which do not always provide adequate comfort for animals;
- The transport of animals is the subject of precise regulations. Nonetheless live animal are transported over significant distances (e.g. calves from the Central Massif to northern Italy, piglets from Denmark to Germany, export of life beef from Ireland, etc.) These transports are the result of specialization of farmers in one step of the animal's life or the management of environmental issues. However social pressure might affect these organisations in the future;
- At slaughter, techniques for stunning animals are progressively generalized to induce a state of unconsciousness in animals, that is to say their inability to feel pain and negative emotions in response to the last adopted regulation (EC N° 1099/2009) which imposes an objective of results. Although considerable efforts have been made, articles and NGOs still relate some shortcomings. Reducing animal stress is also important for the safety of the staff and for meat quality.

Animals are now recognized as sentient beings at member state and EU level[81]. Several directives reflect this recognition[82] and aim to develop a preventive approach to the whole of the rearing conditions, transport and slaughter of animals. Most of the regulations are based on the five principles[83] which must be respected to guaranteeing the welfare of animals on farms. The definition of welfare is in itself a difficult question. Today ethicists and physiologists agree that welfare must refer to the mental state of the individual in its environment and therefore does not only refer to positive human actions towards animals (good animal care) which is a necessary condition but whose result must be evaluated at

[80] BBFAW, 2016. The Business Benchmark on Farm Animal Welfare. https://www.bbfaw.com/media/1450/bbfaw-2016-report.pdf.

[81] Registered in the Amsterdam Treaty of the EU in 1997.

[82] Mormède P., Boisseau-Sowinski L., Chiron J., Diedrich C., Eddison J., Guichet J.-L., Le Neindre P., Meunier-Salaun M.-C., 2018. Bien-être animal: Contexte, définition, évaluation. *INRA Prod. Anim*. 31(2): 145-162.

[83] Farm Animal Welfare Council, 1992:absence of hunger and thirst; physical comfort; good health and absence of injury or pain; the possibility of expressing the behaviour normal of the species; the absence of fear and distress.

the animal level to ensure the effectiveness of the measures taken. This mental dimension draws attention to the fact that good health, as well as a satisfactory level of production or a lack of stress, are not enough. It is necessary to take into account what the animal feels, not only unpleasant subjective perceptions (frustration, pain, suffering), but also to seek positive emotions.

The livestock farming systems must evolve in this scientific, social and legal context with two objectives. The first one is to limit and if possible suppress the negative emotions as pain linked to mutilation practices, but also fear and frustration. The second is to favour the positive emotions and the expression of the natural behaviours of the species for example by enriching the living environment of animals[84] or given access to the outdoors. Science can inform the debate by proposing objective indicators of animal welfare based on their internal emotional state as initially proposed by the Welfare Quality® project[85] and by analysing the impacts of different husbandry, transport and slaughter conditions on these indicators. For practical use, many evaluation grids have been developed with varying degrees of complexity according to species, stages of development and environmental conditions. Precision farming technologies make it possible to approach the assessment of well-being by considering the dynamics of phenomena linked to age and / or the development cycle[86]. Beyond technology and animal physiology, the two questions that must be asked are those of determining the optimal level of welfare of farm animals and that of the methods of public intervention allowing this level to be reached at a lower cost for society as a whole[87].

1.5. Consumption of animal products and health

1.5.1. Nutritional benefits and risks of animal products consumption

Overconsumption of animal products may be associated with chronic diseases. The high fat content in animal based food, more specifically saturated fats, has been linked to cardiovascular diseases incidence in epidemiological studies[88]. However some fat found in lean meat and milk (mono and poly unsaturated fatty acids) have shown to be beneficial and recent studies concluded there is no clear link between the reasonable consumption of animal products (including butter) and cardiovascular diseases[89]. Carbohydrate intake may be a

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[84] Boissy A., et al. 2007. "Assessment of positive emotions in animals to improve their welfare." *Physiology & Behavior* 92: 375-397.

[85] Welfare Quality, 2009. Assessment protocol for cattle http://www.welfarequalitynetwork.net/media/1088/cattle_protocol_without_veal_calves.pdf; Assessment protocol for pigs http://www.welfarequalitynetwork.net/media/1018/pig_protocol.pdf; Assessment protocol for poultry http://www.welfarequalitynetwork.net/media/1019/poultry_protocol.pdf (/ funded by the European Commission (2004-2008).

[86] www.eu-plf.eu/.

[87] Farm Animal Welfare Committee, 2011.

[88] Givens D.J., 2018. Review: Dairy foods, red meat and processed meat in the diet: implications for health at key life stages. Animal. 12, 1709-1721.

[89] Guo J., Astrup A., Lovegrove J.A., Gijsbers L., Givens D.J., Soedemah-Muthu S.S. 2017. Milk and dairy consumption and risk of cardiovascular diseases and all-cause mortality: dose response meta-analysis of prospective cohort studies. *Eur. J. Epidemiol.,* 32, 269-287.

larger contributor, even more than saturated fats[90], to chronic diseases. The International Agency for Research on Cancer (IARC)[91] classified, the consumption of red meat as "probably carcinogenic to humans" and the consumption of processed meat as "carcinogenic to humans". It is the positive association with the risk of occurrence of colorectal cancer which justified this classification, on the basis of risks increased by 17% for each additional consumption of 100 grams of red meat per day and by 18% for each additional consumption of 50 grams of processed meat per day. Even if these consumption levels are much (two times or more) higher than those observed, it remains true that in Italy, around 4 000 annual deaths linked to colorectal cancers are attributable to the average daily consumption combined 61 g of red meat and 27 g of processed meat[92]. Considering these data and while awaiting an evolution in the transformation processes, the WHO recommends limiting the consumption of red meat and avoid, as much as possible, that of processed meat.

The potential negative health impacts linked to overconsumption of meat/animal products should be weighed against their nutritional benefits. Animal products remain food of choice to easily benefits of well-balanced diets. Animal based food are unique source and/or are very rich in several micro nutrients (vit B12, A, B3, B6 and D, zinc, selenium, calcium, phosphorus and heme iron) and various bioactive components (taurine, creatine, camosine, conjugated linoleic acids) which can offer nutritional benefits including development of cognitive functions[93]. Animal products are notably highly recommended for specific population: for older people where meat consumption aimed at limiting the risks of sarcopenia[94] by providing proteins of high nutritional quality which have a more anabolic (effect on muscle mass) than a similar dose of plant protein; for early years of life as they have beneficial effect on physical and cognitive of development[95], for women of childbearing age to prevent deficiencies[96] (i.e. depletion of iron reserves). Alternatively, meat restriction and diets which avoid animal products may result in borderline to severe nutritional deficiencies and

[90] Jensen R.G., 2000. Fatty acids in milk and dairy products. Fatty acids in foods and their health implications. (Ed.2), 109-123.

Barclay A.W., Petocz P., Mc Millan-Price J., Flood V.M., Prvan T., Mitchell P., Brand-Miller J.C., 2008. Glycemic index, glycemic load and chronic disease risk. A meta-analysis of observational studies. *Am. J. Epidemiol.*, 147, 755-763.

[91] Bouvard V., Loomis D., Guyton K. Z., Grosse Y., Ghissassi F. E., Benbrahim-Tallaa L., Guha N., Mattock H., Straif K., 2015. Carcinogenicity of consumption of red and processed meat. *Lancet Oncology* 16:1599-1600.

[92] Gallus S., Bosetti C., 2016. Meat consumption is not tobacco smoking. International Journal of Cancer (Letter to the Editor) 138(10): 2539-2540.

[93] Leroy F., Cofnans N. 2019. Should dietary guidelines recommend low red meat intake?, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2019.1657063.

[94] Rolland Y. 2003. Sarcopenia, calf circumference, and physical function of elderly women: a cross sectional study. J Am. Geriatr Soc 51, 1120–1124.

[95] Balehegn M., Mekuriaw Z., Miller L., McKune S., Adesogan T., 2019. Animal sourced foods for improved cognitive development. *Animal Frontier*, 9, 51-57.

Louwman M.W., van Dusseldrop M., van de Vijver F.J., Thomas C.M., Schneede J., Ueland P.M., Refsun H., van Staveren W.A. 2005. Signs of impaired cognitive function in adolescent with marginal cobalamin status. *Am. J. Clin. Nutr.,* 72, 762-769.

[96] Fayet F., Flood V., Petocz P., Samman S., 2014. Avoidance of meat and poultry decreases intakes of omega-3 fatty acids, vitamin B12, selenium and zinc in young women. *J Human Nutr Diet.*, 27 (Suppl. 2), 135–142.

B12, selenium and zinc in young women. *J. Human Nut. Dietetics* 27:135–142.

various negative health outcomes[97] notably when people are not diligent for supplementation. Milk and dairy foods are key sources of important nutrients (Ca, Mg, I) for bone development, whose low supply in adolescence may not be apparent until later life, particularly in post-menopausal women. Therefore, given the growing burden of non-communicable diseases, consumption of red meat, and particularly processed red meat, should be reduced where it is high and moderate amounts of unprocessed red meat and other non-red meat are an important source of nutrients, and their reduction should not be done at the expense of increasing the risk of undernutrition among the most vulnerable.

1.5.2. Zoonotic and foodborne diseases transmissions

Animal diseases can cause serious social, economic and environmental damage and in some cases threaten human health. Some emerging infectious diseases in humans are of livestock origin and are classified as zoonosis (H1N1, H5N1 flu, HIV, etc.) and some are due to direct human contamination with pathogens that circulate in wildlife (Ebola, sudden acute respiratory syndrome (SARS), COVID19, etc) that do not seem to have livestock as intermediary host[98]. The pathogens causing these diseases have wildlife reservoirs that serve as their long-term hosts and pathogen circulates at the wildlife, livestock and human interface (Figure 16). In addition to the appearance of new infectious agents, the rapid expansion and worldwide spread of new antibiotic resistance genes, or new mobile genetic carriers carrying one or more resistance genes, is another form of emergence[99], in which farming plays an important role (see also Figure 16). It was estimated, from a 2015 survey, that antimicrobial resistance was responsible of around 33 000 Europeans deaths[100]. In that sense, emerging pandemics are considered as one of the most important risks for society (the COVID-19 outbreak is unfortunately a demonstration). Zoonosis threatens economic development, animal and human well-being, and ecosystem integrity. The livestock sector must also face an increasing number of major disease threats which are not zoonotic but are global in scale, have the potential of rapid spreads irrespective of the national borders and are devastating (e.g. the current case of African swine fever).

[97] Burkert N.T., Muckenhuber J., Großsch€adl F., Asky E.R., Freidl. W. 2014. Nutrition and health – the association between eating behavior and various health parameters: a matched sample study.PLOS ONE 9 (2):e88278. doi: 10.1371/journal.pone.0088278.

Key T.J., Appleby P.N., Rosell M.S. 2006. Health effects of vegetarian and vegan diets. *Proc.Nutr.Soc.,* 65, 35 – 41.

De Smet S., Vossen E. 2016. Meat: The balance between nutrition and health. A review 120, 145–156.

Yen H. W., Li Q., Dhana, A., Li, T., Qureshi A., Cho E., 2018. Red meat and processed meat intake and risk for cutaneous melanoma in white women and men: two prospective cohort studies. Journal of the American Academy of Dermatology 79 (2):252–257. DOI: https://doi.org/10.1016/j.jaad.2018.04.036.

[98] Blancou J.B., Chomel B., Belotto A., Meslin F.X. 2005. Emerging or re-emerging bacterial zoonosis: factors of emergence, surveillance and control. *Vet Res*., 36, 507-522.

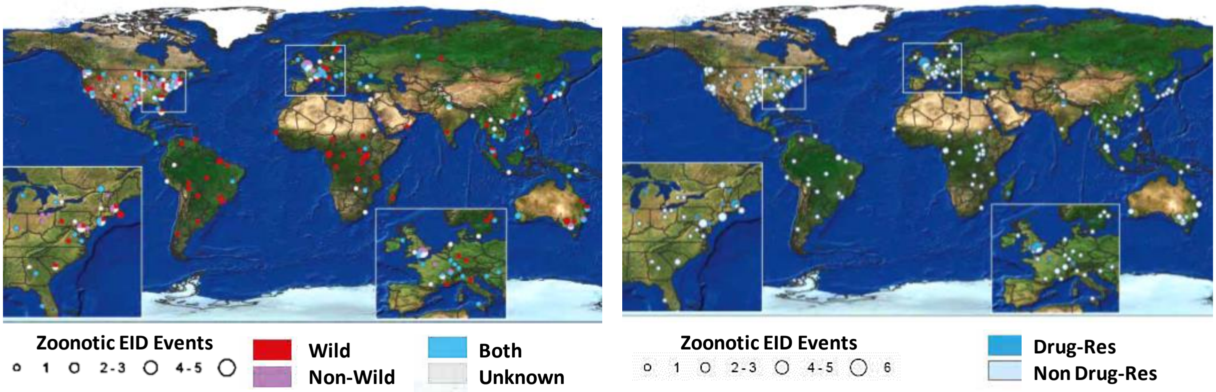
[99] http://www.euro.who.int/fr/health-topics/disease-prevention/antimicrobial-resistance/antibiotic-resistance

[100] Cassini A., Diaz Högberg L., Plachouras D ., Quattrocchi A., Hoxha A., Skov Simonsen G., Colomb-Cotinat M., Kretzschmar M.E., Devleesschauwer B., Cecchini M., Ait Ouakrim D., Cravo Oliveira Y., Struelens M.J., Suetens C., Monnet D.L., the Burden of AMR Collaborative Group. 2019. Attributable deaths and disability-adjusted life-years caused by infections with antibiotic-resistant bacteria in the EU and the European Economic Area in 2015: a population-level modelling analysis. *Lancet Infect Dis* 19, 56–66.

These threats are of major importance in the international trade of animals and animal products.

Since we can never foresee all disease emergences, it is essential to address the causes underlying these emerging, and their speed of propagation. The intensive farming systems may facilitate the transmission of epidemics with animal density and organization segmented pathways that causes the movement of animals between farms and between countries. Animals in extensive systems are more exposed to some pathogens, but may cope better with other ones. These limits, and the societal demand for improved animal welfare (see 1.4), will undoubtedly lead to some reorganization of these systems and the development of agroecological approaches which aim to control the balances of microbial ecosystems: new strategies for controlling the balance of the microbial ecosystem for the benefit of animal, livestock, environmental and human health and monitoring of pathogens (early detection, traffic monitoring, identification of sources of transmission).

Figure 16: Events of zoonotic disease emergence classified by type animal host (left) and in term of drug resistance (right)[101]



Source: Grace et al, 2012[101]

Foodborne pathogens (e.g. Salmonella or Listeria) are another ongoing burden which have a health impact comparable to malaria, tuberculosis or HIV/AIDS according to WHO[102] and almost 98% of this burden falls on developing countries and particularly on children.

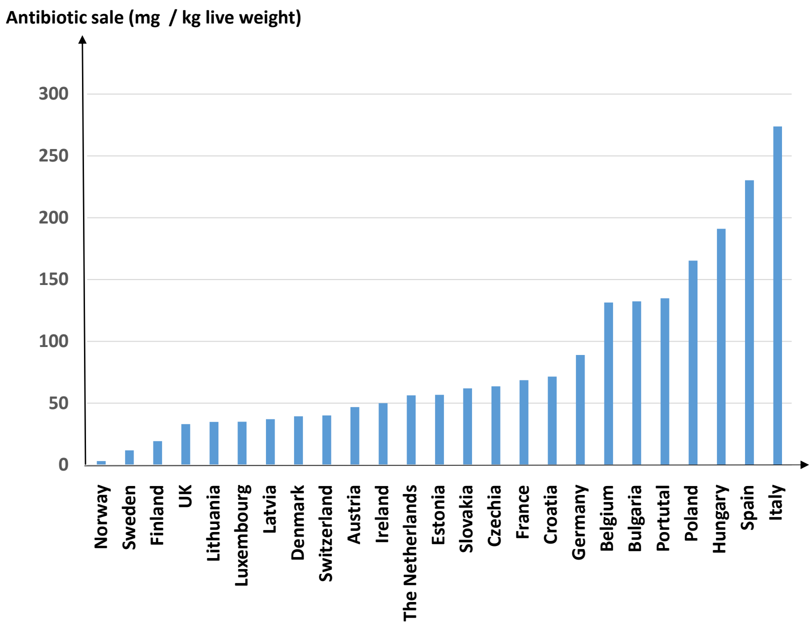
[101] Grace D., Mutua F., Ochungo P., Kruska R., Jones K., Brierley L., Lapar L., Said M., Herrero M., Pham D.P., Nguyen B.T., Akuku I., Ogutu F. 2012. Mapping of poverty and likely zoonoses hotspots. Zoonoses Project 4. Report to the UK Department for International Development. Nairobi, Kenya: ILRI. https://cgspace.cgiar.org/bitstream/ handle/10568/21161/ZooMap_July2012_final.pdf.

[102] Havelaar A.H., Kirk M.D., Torgerson P.R., Gibb H.J., Hald T., Lake R.J., Praet N., Bellinger D.C., de Silva N.R., Gargouri N., Speybroeck N., Cawthorne A., Mathers C., Stein C., Angulo F.J., Devleeschauwer B.,2015. World Health Organization Foodborne Disease burden epidemiology reference group. World Health Global estimate and regional comparisons of the burden of foodborne disease in 2010. PloS Med. 12:e10001923. DOI: https://doi.org/10.1371/journal.pmed.1001923.

1.5.3. Reducing the use of antimicrobials is underway

As humans and animals share the same pharmacopoeia, it is important to reduce the use of antibiotics in livestock farming to reduce the risk of antibiotic resistance. The EU banned the use of antibiotics as growth promoters in 2006 and decided to ban their prophylactic uses from 2022, this latter use representing half of the total consumption. The overall decline in sale of antibiotics between 2011 and 2017 was 32%, overall sales falling from 162 to 109 mg active ingredient/kg live weight[103]. In particular, two of the most critically important classes of antibiotics for human medicine decreased rapidly (polymyxins, 3rd- and 4th-generation cephalosporins). This show that EU guidance and national campaigns promoting prudent use of antibiotics in animals are having a positive effect. However, we must emphasize the great intra-European variability in the use of antibiotics in animal husbandry (Figure 17), in a range going from more than 200 mg/kg for some countries (Hungary, Spain, Italy) to less than 20 mg/head in three Nordic countries (Norway, Sweden, Finland). The differences might be partly related to the development of organic farming (Nordic countries), different compositions of animal populations, varying farming intensities but above all by more or less targeted use of antibiotics and farmers capabilities. For example, antibiotic sales is low in some intensive farming systems (Denmark). This figure show that margins of progress are still large.

Figure 17: Sales of veterinary antimicrobial agents (mg/kg Live Weight) in European countries in 2017



Source: European Medicine Agency, 2019[103]

[103] European Medicine Agency, 2019. Sales of veterinary antimicrobial agents in 31 European countries in 2017. Trends from 2010 to 2017. Ninth ESVAC report, 109p. www.ema.europa.eu.

1.6. Assessment of livestock systems and consumption patterns: methodological insights

The assessment of livestock farming systems is often carried out using life cycle analysis (LCA) and life cycle thinking is increasingly seen as a key concept for ensuring a transition towards more sustainable production and consumption patterns. The defining feature of LCA is that it quantifies the impacts arising over the life-cycle, thereby enabling a more comprehensive understanding of a product's environmental impact. LCA approach can be applied at any scale from the farm level to national[104], EU[105] or even global[106].

1.6.1. Assessment of the livestock farming systems

Studies using Life Cycle Analysis (LCA) have consistently shown the impacts of livestock farming. An extensive review of literature[107] showed that LCA studies of livestock products in OECD countries yielded a consistent range of results for use of land and energy, and for climate change, i.e. that production of one kg of beef used more land and energy and had highest global warming potential (GWP), followed by production of 1 kg of pork, chicken, eggs, and milk. However, meat, milk and eggs have different nutritional values per kg. When these impacts were measured per kg of protein (rather than per kg of product) beef still had the highest impact, but the differences between the other commodities were less marked. No clear effect was found for eutrophication and acidification. A more recent paper[108] reviewing 570 studies drew similar conclusions, i.e. that per unit of protein: (a) ruminants have much higher impacts in terms of GWP and land use than other livestock commodities, (b) within ruminant production, dairy has a lower impact than suckler beef or lamb, (c) trends within livestock for other impacts were less marked, (d) grains have a lower impact than livestock for all impacts except water use. In addition, they made the following points:

- "The farm stage dominates, representing 61% of food's GHG emissions (81% including deforestation), 79% of acidification, and 95% of eutrophication".
- The results show the high variation in impact among both products and producers.
- "Of the nine changes assessed, only two (changing from monoculture to diversified cropping and improving degraded pasture) deliver statistically significant reductions in both land use and GHG emissions."

[104] Leinonen 2012. Predicting the environmental impacts of chicken systems in the United Kingdom through a life-cycle assessment: broiler production systems.

[105] Lesschen J.P., van den Berg M., Westhoek H.J., Witzke H.-P., Oenema O. 2011. Greenhouse gas emission profiles of European livestock sectors. *Anim. Feed Sci. Technol.*, 166–167, 16–28, doi:10.1016/j.anifeedsci.2011.04.058.

[106] MacLeod M. J., Vellinga T., Opio C., Falcucci A., Tempio G., Henderson B., Makkar H., Mottet A., Robinson T., Steinfeld H., Gerber P.J., 2017. Invited Review: A Position on the Global Livestock Environmental Assessment Model (GLEAM). *Animal* 12 (2) 383-397 DOI: https://doi.org/10.1017/S1751731117001847.

[107] de Vries M., de Boer I.J.M. 2010. Comparing environmental impacts for livestock products: A review of life cycle assessments *Livestock Sci.,* 128 (2010) 1–11.

[108] Poore J., Nemecek T. 2018. Reducing food's environmental impacts through producers and consumers. *Science* 360 (6392), 987-992 DOI: http://doi.org/10.1126/science.aaq0216

- "The impacts of the lowest-impact animal products exceed average impacts of substitute vegetable proteins across GHG emissions, eutrophication, acidification (excluding nuts), and frequently land use."

While LCA can be a useful analytical approach, it has some weaknesses when applied to food and further improvements are needed to ensure robust support for decision making in both business and policy development contexts.

- **LCA has a narrow perspective of agricultural systems which prevent a balanced assessment of agroecological systems.** Originally developed for industrial products, LCA focuses on reduced impacts per unit of product. This approach favours intensive systems at the expense of agro-ecological and organic systems, and doesn't fully reflect the broader role of agriculture and livestock farming for society and nature[109]. LCA struggles to comprehensively assess some aspects that are critical for long-term sustainable food production and the preservation of natural capital such as soil fertility (structure, organic C content, hydrology) soil erosion; biodiversity impacts[110]; toxicity impact of pesticides for soil, environment, biodiversity and human exposure and health; provision of other ecosystem services such as employment and cultural related aspects. Some livestock farming systems (e.g. grassland based ruminants) can contribute very positively to many of these functions.
- **LCA does not fully capture some important properties that emerge at the landscape level** and thus cannot consider the role of buffer zones (e.g. humid grassland) to regulate flow of nutrients or the maintenance of habitats to preserve biodiversity. It is also difficult, if not impossible, to foresee the overall consequences in the food system and landscape of a shift in consumer demand toward less meat ignoring the many roles of livestock farming and grasslands at landscape level. It is also difficult to accurately quantify environmental impacts that are context-dependent. The spatialisation of LCA remains a methodological issue, even if certain frameworks have been proposed[111].
- **Functional units also raise some concerns**. The functional unit used to express impacts affects the results and needs to be chosen carefully. For example when the C-footprint are expressed in kcal, fruits and vegetables are as impacting (or even a little more) than dairy products (Figure 18)[112]. Another example would be that the carbon footprint of one kg of cow-milk is higher than that of one kg of soy milk, however cow's milk and soy milk have quite different

[109] van der Werf H.M.G., Knudsen M.T., Cederberg C. 2020. Towards better representation of organic agriculture in life cycle assessment. *Nat Sustain* DOI: https://doi.org/10.1038/s41893-020-0489-6.

Notarnicola B., Sala S., Anton A., McLaren S.J., Saouter E., Sonesson U. 2017. The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. *J. Cleaner Prod.* 140. 399-409.

[110] Souza D.M., Teixeira R.F., Ostermann O.P. 2015. Assessing biodiversity loss due to land use with Live Cycle Assessment: are we there yet? *Glob. Chang. Biol*., 21, 32-47. doi:10.1111/gcb.12709.

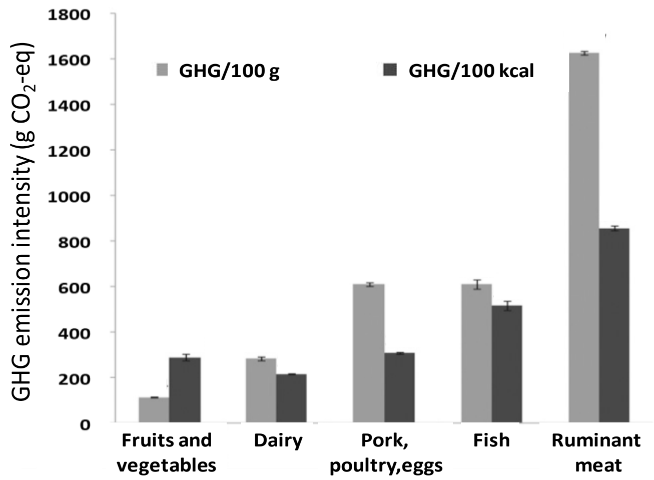
[111] Nitschelm L., Aubin J., Corson M.S., Viaud V., Walter C. 2016. Spatial differentiation in Life Cycle Assessment LCA applied to an agricultural territory: current practices and method development. *J. Clean Prod.*, 112, 2472-2484.

[112] Vieux F., Soler L.G., Touaz D., Darmon N. 2013. High nutritional quality is not associated with low greenhouse gas emissions in self-selected diets of French adults. *Am. J. Clin. Nutr*., 97:569–83.

nutritional contents[113], so comparing the impact per kg is arguably not comparing like with like.

- **Co-production is another common issue for C footprint estimates**. Different allocation methods will provide different results. In the absence of a system expansion approach (which avoids allocation but is more demanding on date collection[114]) the PEF initiative[115] (Product Environmental Footprint) can contribute to more balanced allocation methods.

Figure 18: Mean GHG intensity emission related to the consumption of 100 g or of 100 kcal of food



Source: PEF initiative[116]

1.6.2. Assessment of the sustainability of food systems

For FAO[117], sustainable diets are defined as nutritionally adequate, healthy, safe, culturally acceptable, economically viable, accessible and affordable, protective and respectful of biodiversity and ecosystems. Nevertheless the term sustainable refers only to the environmental dimension of the diet in many publication like the EAT-Lancet.

Increasing sustainability by reducing meat consumption is not as simple as it is sometimes presented. Studies often start from simplistic assumptions about the environmental impact of commodities and the substitutability of livestock commodities with non-meat alternatives. Reducing meat is the preferred

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113 Smedman A., Lindmark-Månsson H., Drewnowski A., Modin Edman A.K. 2010. Nutrient density of beverages in relation to climate impact *Food & Nutrition Res.,* 54:1, 5170, DOI: https://doi.org/10.3402/fnr.v54i0.5170.

114 Cederberg C., Stadig M. 2003. System Expansion and Allocation in Life Cycle Assessment of Milk and Beef Production. The International *J. Life Cycle Assess.,* 8(6):350-356. DOI:https://doi.org/10.1007/BF02978508.

115 https://www.petcore-europe.org/projects/33-product-environmental-footprint-pef-european-initiative.html

116 https://www.petcore-europe.org/projects/33-product-environmental-footprint-pef-european-initiative.html

117 FAO. 2010. Definition of sustainable diets. International scientif symposium "Biodiversity and sustainable diets. United against hunger", 2010, 3-5 nov 2010, FAO Headquarters, Rome.

scenario given the high C footprint of meat and its alleged negative health effects[118]. A purely plant-based diet can thus be considered to be sustainable[119] without consideration being given to changes in nutritional content, which may necessitate supplementation (see 1.5.1). In addition, the diets proposed deviate considerably from the usual food consumption in different parts of the world, which raises questions about their social and cultural acceptability. Finally, the proposed diets can be unaffordable for 1.6 billion inhabitants on Earth[120].

Epidemiological studies based on food consumption actually observed in the population are better able than studies based on theoretical scenarios to propose regimes with low environmental impacts respecting the economic and cultural aspects of the sustainable diet concept. They show the different dimensions of sustainable diet are not necessarily compatible with each other[121] and some compromises should be found. In particular, the compatibility between nutritional adequacy and less impact is not systematically acquired. For example reducing the consumption of meat so as not to exceed 50 g/d reduces the diet C-footprint by 12% but also reduces energy intake (-133 kcal/d) for typical French diets. When this energy deficit is compensated by plant based products (i.e. isocaloric diets), the difference in diet C-footprint is reduced and it is reversed when it is compensated by fruits and vegetables (+ 3%), although their undisputable nutritional interest remains because the quantity of fruits and legume to consume (426 g/d) is large[122]. However, the increase in the consumption of fruit and vegetables leads, due to income elasticities and cross-price elasticities, to a decrease in the consumption of other products, in particular meat.

By focusing on the cost and impact of producing plant based food versus animal based food, the current debate is an overly simplistic view of both agriculture and nutrition. This approach is purely arithmetic (sum of inventory data of various food) and ignores the agronomic and ecological effects induced by substitution in land use; it does not account for the considerable variability in inventory data between production systems and management practices. It also

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118 Roos E., Karlsson H., Witthoft C., Sundberg C. 2015. Evaluating the sustainability of diets - Combining environmental and nutritional aspects. *Environ. Sci. Policy* 47, 157e166.

Westhoek H., Lesschen J.P., Rood T., Wagner S., De Marco A., Murphy-Bokern D., Leip A., van Grinsven H., Sutton M., Oenema O. 2014. Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. *Global Environmental Change* 26, 196–205.

Auestad N., Fulgoni V.L. 2015. What current literature tells us about sustainable diets: Emerging research linking dietary patterns, environmental sustainability, and economics. Advances in Nutrition: *An International Review Journal*, 6(1), 19–36.

119 Springmann M., Wiebe K., Mason-D'Croz D., Sulser T.B., Rayner M., Scarborough P. 2018. Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. *Lancet Planet. Health*, 2, e451ee461.

120 Hirvonen K., Nai Y., Headey D., Masters W.A. 2020. Affordability of the EAT–Lancet reference diet: a global analysis. Lancet Glob Health, 8: e59–66.

121 Perignon M., Masset G., Ferrari G., Barré T., Vieux F., Maillot M., Amiot M.J., Darmon N. 2016. How low can dietary greenhouse gas emissions be reduced without impairing nutritional adequacy, affordability and acceptability of diet? A modelling study to guide sustainable food choices. *Public Health Nutr.*, 19(14): 2662-2674.

122 Vieux F., Darmon N., Touazi D., Soler L.G. 2012. Greenhouse gas emissions of self-selected individual diets in France: Changing the diet structure or consuming less? *Ecol Econ*, 75, 91-101.

Perignon, M., Vieux, F., Soler, L.-G., Masset, G., & Darmon, N. 2017. Improving diet sustainability through evolution of food choices: Review of epidemiological studies on the environmental impact of diets. *Nutrition Reviews*, 75(1), 2–17.

ignores that the diets that may be the most beneficial for the environment could lead to nutrient deficits[123]. The complexity of making recommendations on sustainable diets is further complicated as some products which are particularly low in emissions because of their plant-based origin, such as refined cereals and high fat/high sugar products have a poor nutritional profile[124]. Finally reducing food intake in accordance with energy balance can lead to a sharp decrease of GHG emission with no modification of the diet composition[125]. These facts call for prudent conclusion before any recommendations for drastic changes in diet composition and livestock production. There is no one single measure for keeping food system within environmental limits and this will require various actions including a moderate reduction in meat consumption in western type diets[126].

2. Evolution of the livestock sector: past trends and drivers of change

2.1. Past trends: how did we get here?

Since the Second World War, the policy drive to ensure stable supplies of affordable food has profoundly changed traditional livestock farming. Agriculture has been engaged in a vast process of modernization and intensification notably based on mechanization, land consolidation, farm enlargement, the use of synthetic inputs and other innovations developed by research.

2.1.1. Increase in productivity and specialisation of farming systems and territories

The Green Revolution brought enormous productivity and production efficiency gains. Efforts have focused on maximizing production per animal and reducing costs. Productivity gains have been rapid and steady due to genetic improvement of animals, development of new husbandry practices based on the confinement of animals in buildings, development of high quality feed and additives and improvement of animal health. This evolution was favoured by an era of cheap energy. Progress was enormous: the feed conversion ratio of chicken has decreased from 2.2 in late '60s to 1.6 or less today while the growth rate has

[123] Meier T., Christen O. 2013. Environmental impacts of dietary recommendations and dietary styles: Germany as an example. *Envir. Sci. Technol.*, 47(2), 877–888.

[124] Payne C. L., Scarborough P., Cobiac L. 2016. Do low-carbon-emission diets lead to higher nutritional quality and positive health outcomes? A systematic review of the literature. *Public Health Nutrition*, 1–8.

[125] Hendrie G., Baird D., Ridoutt B., Hadjikakou M., Noakes M. 2016. Overconsumption of energy and excessive discretionary food intake inflates dietary greenhouse gas emissions in Australia. *Nutrients*, 8(12), 690.

Masset G., Vieux F., Verger E. O., Soler L.-G., Touazi D., Darmon N. 2014. Reducing energy intake and energy density for a sustainable diet: A study based on self-selected diets in French adults. *Am. J. Clinic. Nut.*, 99, 1460–1469.

[126] Röös E, Bajželjb B., Smith P., Pateld M., Littlee D., Garnett T. 2017. Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures. *Global Environmental Change* 47, 1–12.