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).

July 2020

EUROPEAN COMMISSION

Directorate-General for Agriculture and Rural Development
Direction C - Strategy, simplification and policy analysis

Unit C2 - Analysis and Outlook
Contact content: agri-outlook@ec.europa.eu

Unit C.4 - Monitoring and Evaluation
Contact dissemination: AGRI-EVALUATION@ec.europa.eu

European Commission
B-1049 Brussels

Study on

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

Final report

Acknowledgements

This study was initiated and funded by the European Commission.

Authors:

Dr Jean-Louis Peyraud - Deputy Scientific Director Agriculture, INRAE, France

Dr Michael MacLeod - Senior Researcher, Rural Economy, Environment and Society Group, SRUC, King's Buildings, Edinburgh, UK

Michael MacLeod acknowledges support from the Scottish Government's Rural and Environment Science and Analytical Services Division (RESAS) Environmental Change Programme (2016-2021).

Luxembourg: Publications Office of the European Union, 2020

PDF ISBN: 978-92-76-20624-8 doi: 10.2762/3440 KF-02-20-525-EN-N

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.

Table of contents

Tables

Figures

1. Livestock farming today in the EU

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%).

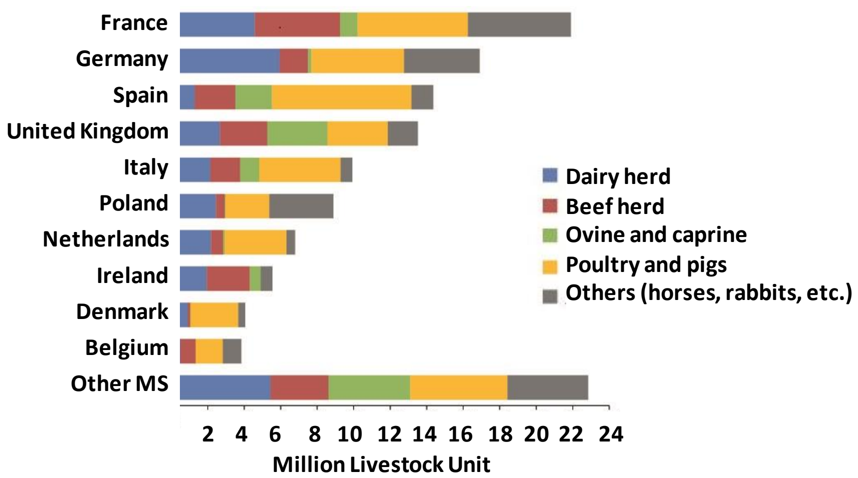
The EU-28 had 131 million livestock units in 2016[2] and more than 50% of these units were concentrated in four countries (Figure 1). Dairy and beef cattle represented more than 50% of the total European herd, the pig herd represented 25% and poultry 15%. The EU differs from other regions of the world 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

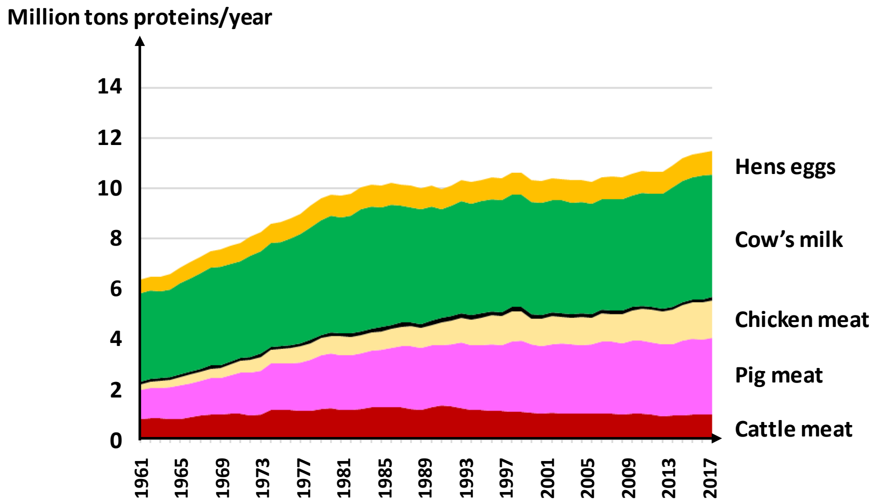


Source: Eurostat[2]

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



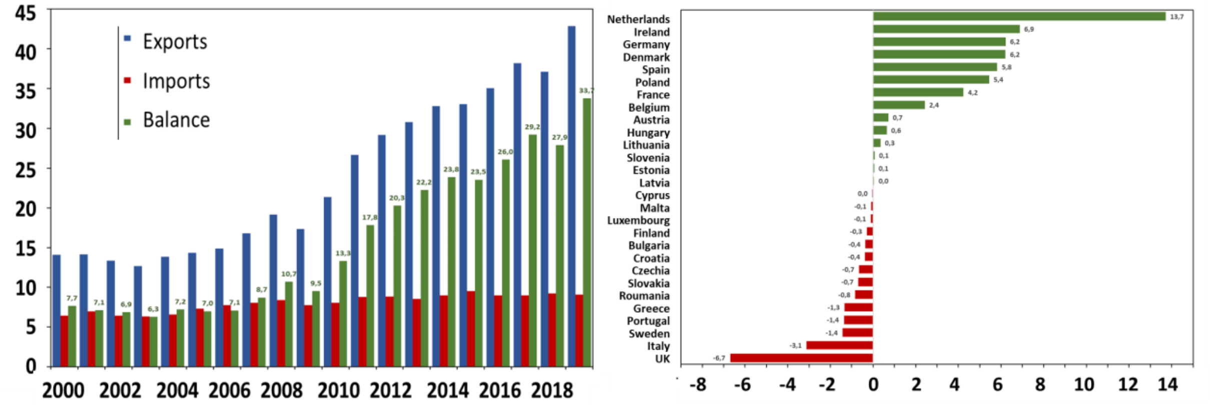
Source: FAO Stat, 2020

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

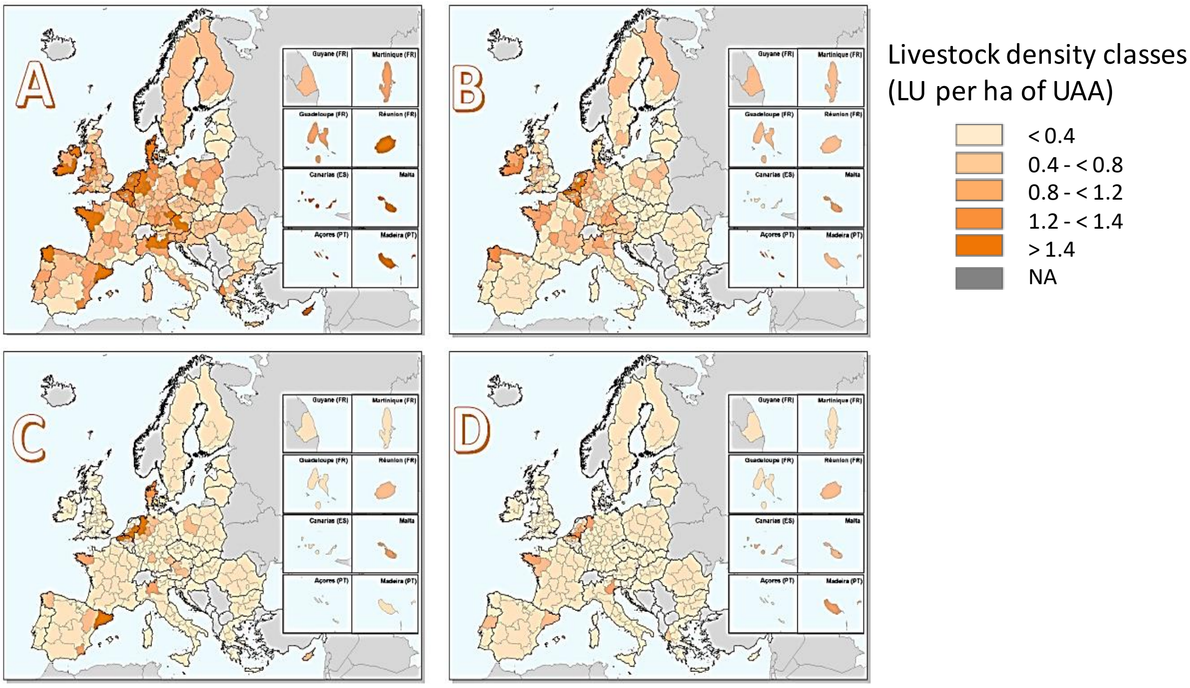
Livestock farming is of crucial importance for many European region and agriculture and 58% of European farms hold animals[2]. European livestock farms employ around 4 million people (salaried and non-salaried), 80% of whom reside in the more recent EU member-states. Mixed crop-and-livestock and dairy 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.



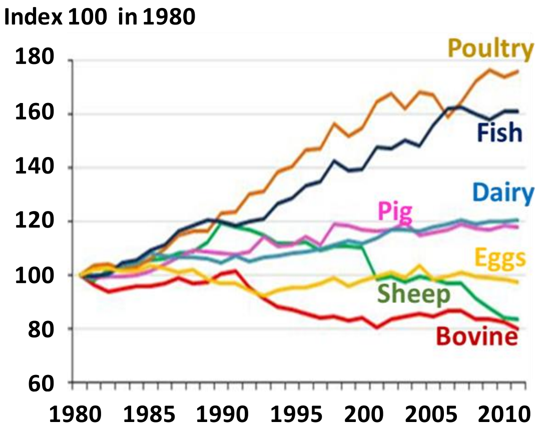
Source: Eurostat, March 2020; maps created by Matteo Sposato, SRUC

[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]

[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/.

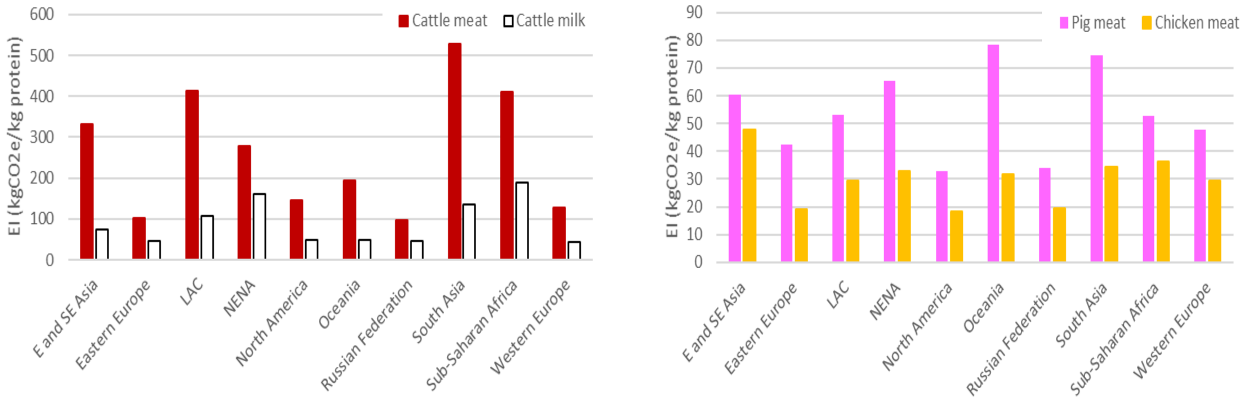
Gerber P.J., Steinfeld H., Henderson B., Mottet A., Opio C., Dijkman J., Falcucci A., Tempio G. 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.

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/).

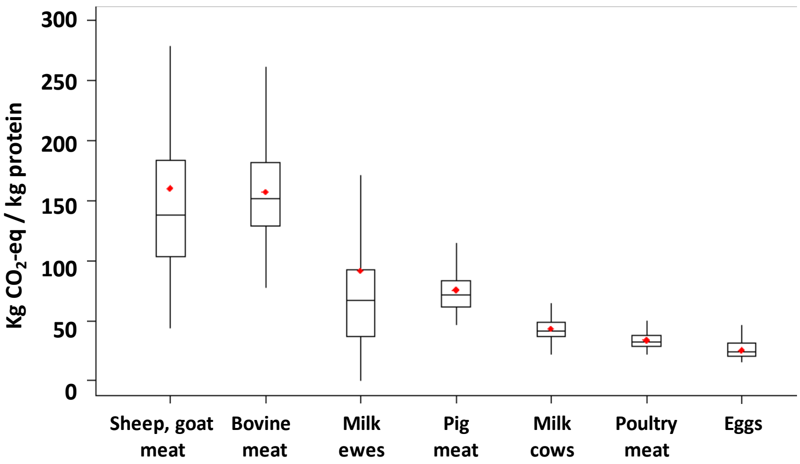
[20] Hilborn R., Banobi J., Hall S.J., Pucylowski T., Walswort T.E., 2018. The environmental cost of animal source foods. *Front Ecol. Environ* 2018; doi:10.1002/fee.1822.

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

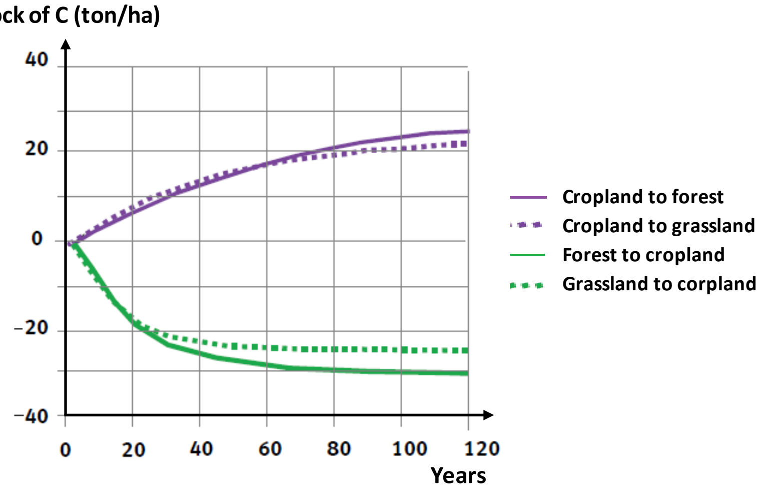
[24] Allen M.R., Shine K.P., Fuglestvedt J.S., Millar R.J., Cain M., Frame D.J., Macey A.H. 2018. A solution to the misrepresentations of CO2-equivalent emissions of short-lived climate pollutants under ambitious mitigation. npj Climate and Atmospheric Science 1:16 ; www.nature.com/npjclimatsci DOI: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

[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.

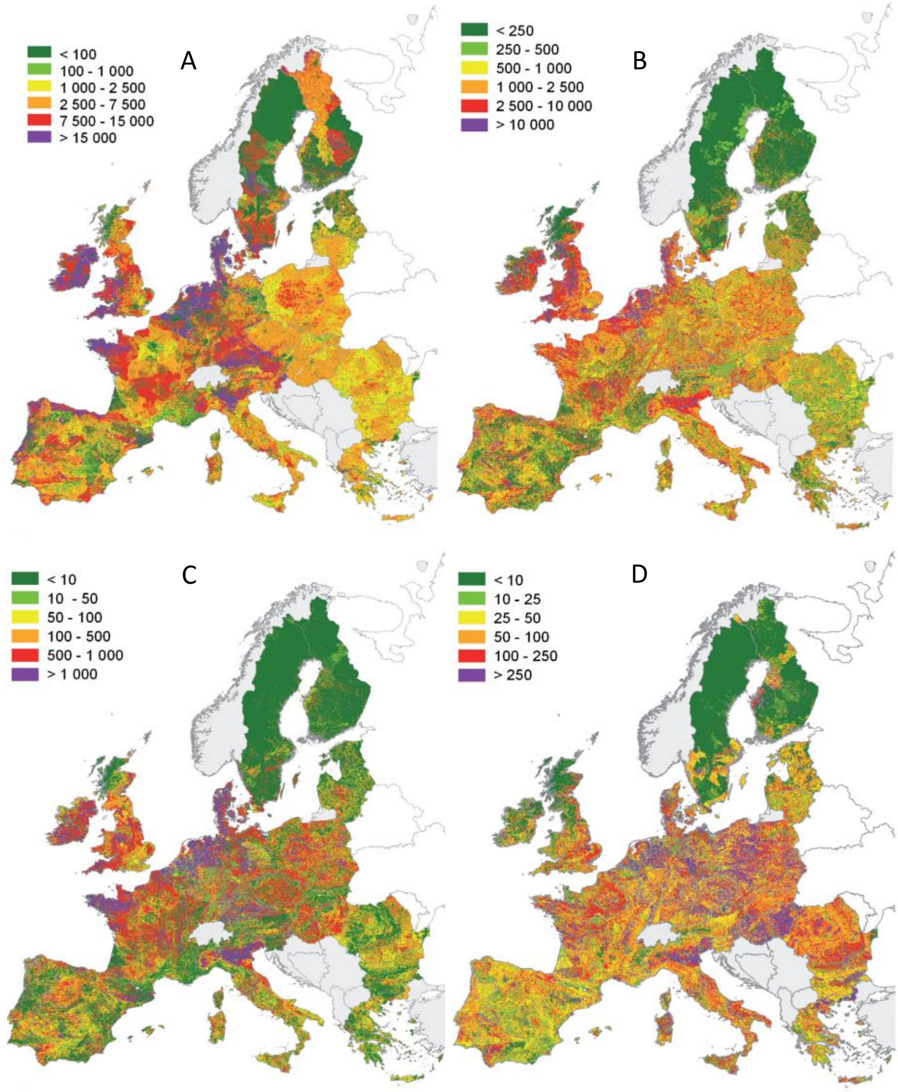
Leip A., Billen G., Garnier J., Grizzetti B., Lassaletta L., Reis S., Simpson D., Sutton M.A., de Vries W., Weiss F., Westhoek H. 2015. Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land use, water eutrophication and biodiversity. Environmental 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]

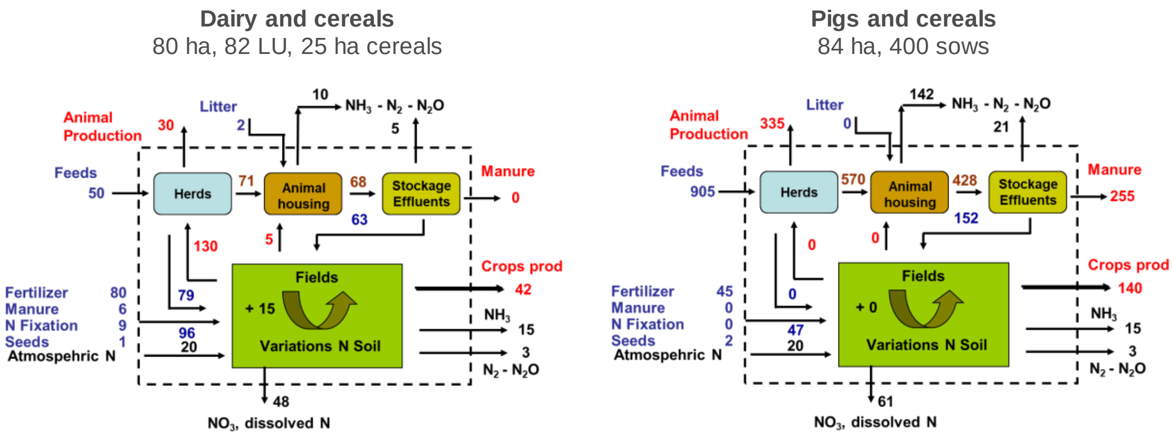
However, the same nitrogen pressure can result in different environmental impacts depending on the sensitivity of the local environment and its capacity to use or transform nitrogen from animal waste (Carrying capacities of territories)[38]. The nitrate content in water does not depend solely on the 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.

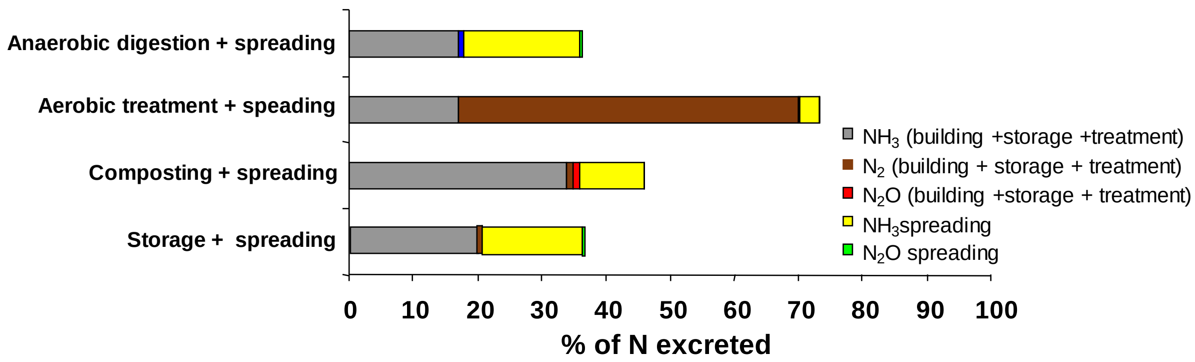
[40] Peyraud J.L., Cellier P., Dupraz P., Aarts F. 2014. Options for the better use of less nitrogen on livestock farms. Advance in Animal Biosciences 5, special issue 1, 55-58.

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

---

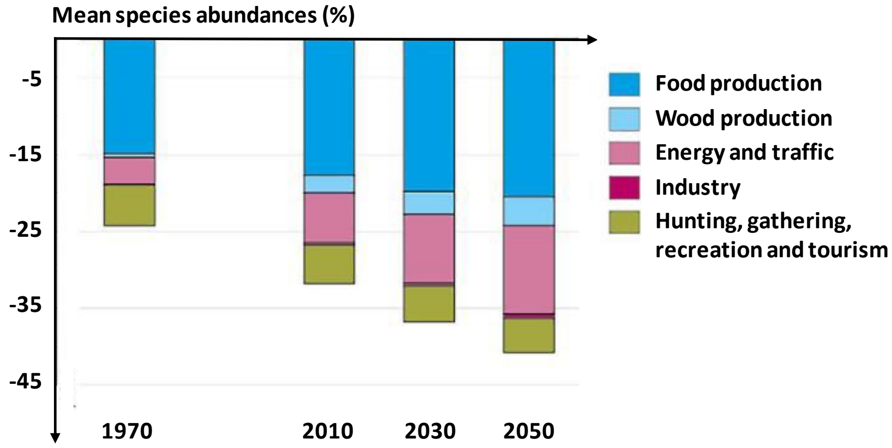
[41] H2020 Feed a gene project, J Van Milgen, coordinator.

[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.

---

[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.

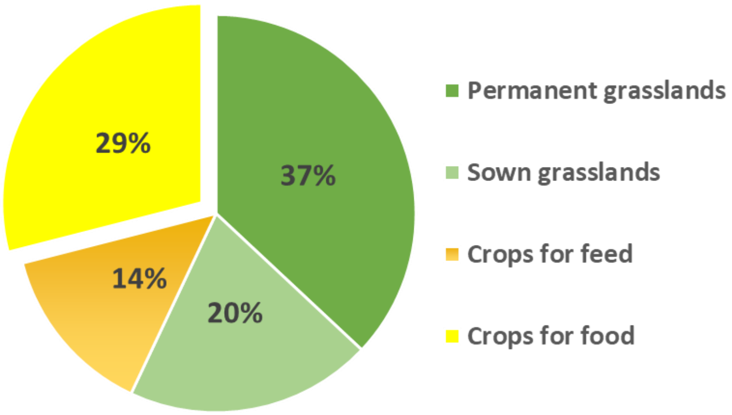
[65] Finley R.L., Collignon P., Larsson D.G.J., McEwen S.A., Li X.Z., Gaze W.H., Reid-Smith R., Timinouni M., Graham D.W., Topp E. 2013. The Scourge of Antibiotic Resistance: The Important Role of the Environment. *Clinical Infectious Diseases*, 57 (5): 704-710.

[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.

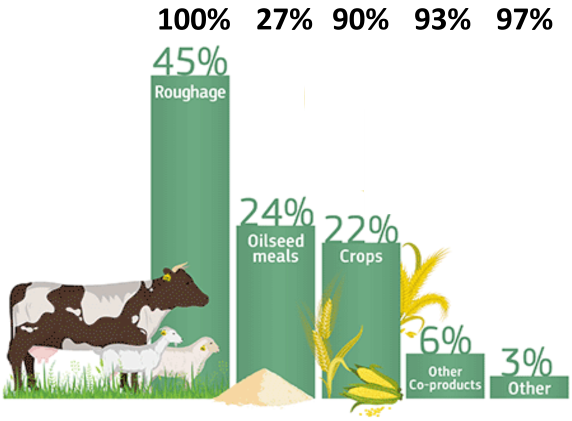
[69] Mottet A., de Haan C., Falcucci A., Tempio G., Opio C., Gerber P. 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security*, 14, 1-18.

[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.

[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.

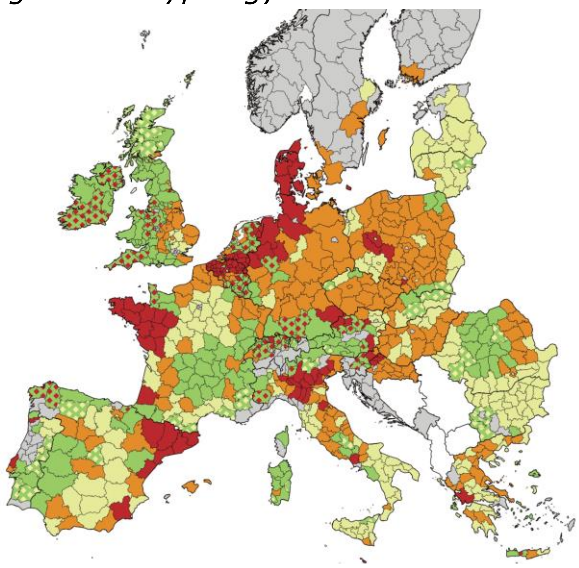
[77] Pfister S., Koehler A., Hellweg S., 2009. Assessing the environmental impacts of freshwater consumption in LCA. *Environ. Sci. Technol.* 43, 4098e4104.

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

---

[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.

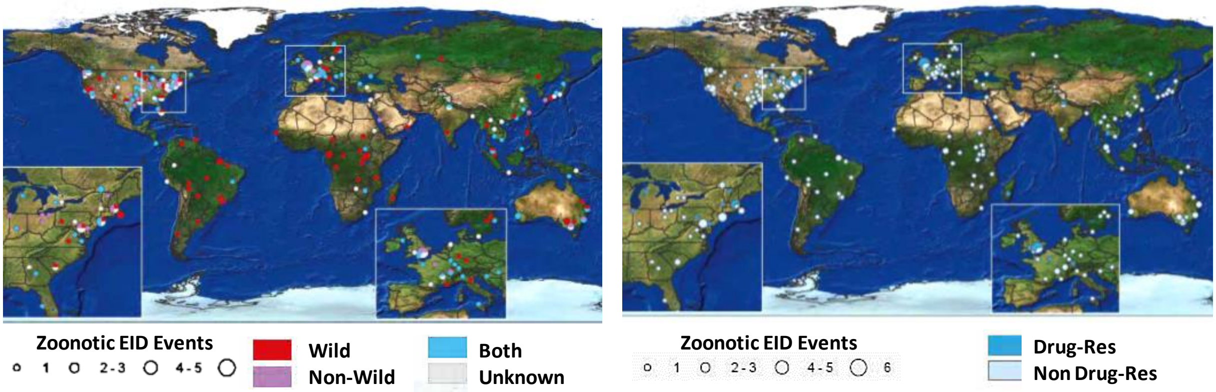
[99] http://www.euro.who.int/fr/health-topics/disease-prevention/antimicrobial-resistance/antibiotic-resistance

[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.

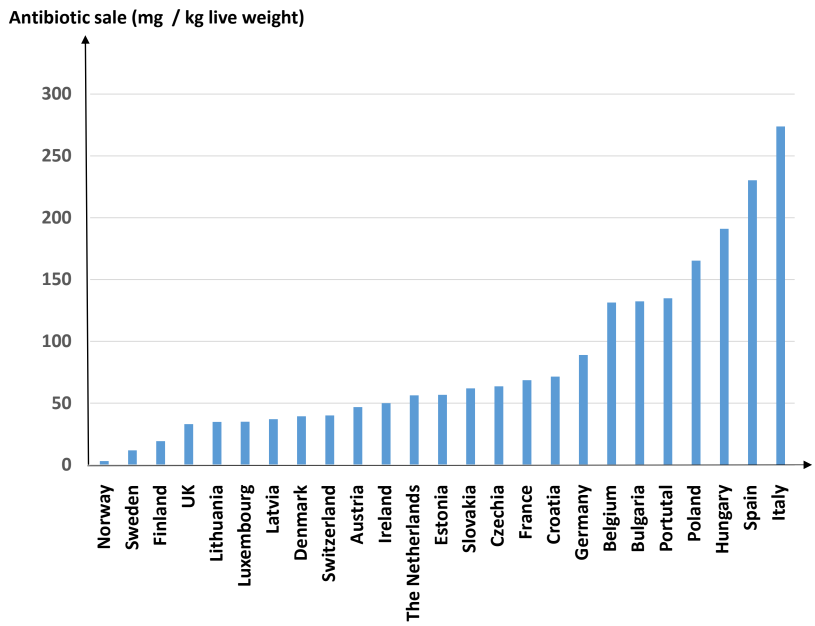
[101] Grace D., Mutua F., Ochungo P., Kruska R., Jones K., Brierley L., Lapar L., Said M., Herrero M., Pham D.P., Nguyen B.T., Akuku I., Ogutu F. 2012. Mapping of poverty and likely zoonoses hotspots. Zoonoses Project 4. Report to the UK Department for International Development. Nairobi, Kenya: ILRI.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

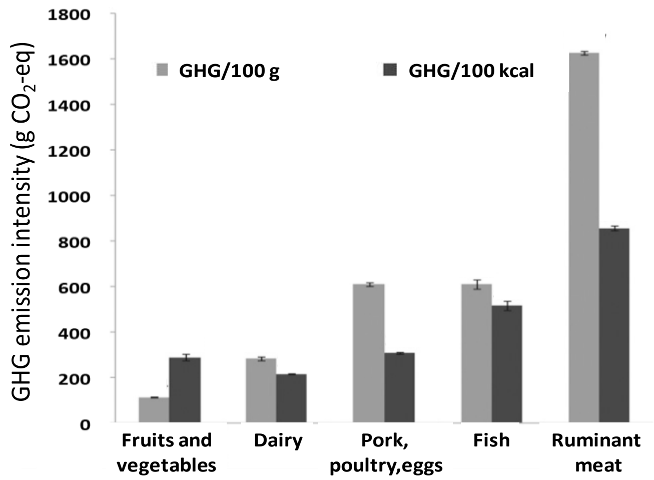
[111] Nitschelm L., Aubin J., Corson M.S., Viaud V., Walter C. 2016. Spatial differentiation in Life Cycle Assessment LCA applied to an agricultural territory: current practices and method development. *J. Clean Prod.*, 112, 2472-2484.

[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

[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

---

[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.

increased by over 400% between 1950 and 2005[127]; the number of piglets produced by sows has increased from 16.4 to 20.6 per year between 1970 and 2016 and the feed conversion ratio of pigs has decreased from 3.80 to 2.37 in the same period[128]. Milk production per cow steadily increased by 100 kg/year or even more. The production of 1 billon kg of milk in 2007 compared to 1944 requires five times less animals, three times less water, 10 times less land, and C footprint of milk is 2.5 time less[129].

The second determining element was the specialization of farms and regions and the decrease in the number of farms. Today, 34% of European holdings are specialized in livestock production (17% ruminants, 5% non-ruminants and 12% with mixed types of animals) while 52% were specialized in cropping and 10% of holdings are now mixed farms with both livestock and crops[130]. Some territories became highly specialized in intensive animal production while other were specialized in crop production and livestock has almost deserted these areas (see figure 7). In the same time the number of holdings has decreased, the size of those who have survived has increased and this evolution is continuing. The number of farms decreased by almost a third between 2005 and 2013[131]. These evolutions occurred at a different rate according to the country and the sector. They were more important in Denmark and Spain than in France and Germany and in the pig sector than in dairy sector.

The mechanisms underlying specialization and concentration are very strong[132] and difficult to counteract. These changes have occurred in response to increased competitiveness that can be achieved from economies of scale and economies of agglomeration whereas the labour costs have increased much more rapidly than the costs of energy, fertilizer, pesticide and land. The geographical proximity of industries and farms results in increased efficiencies (low cost of transporting merchandises, more rapid diffusion of innovation, reinforcement of industry control over suppliers). It is worth noting that the geographical proximity of feedstuffs is not an important factor in the location of livestock farming, especially in the case of pigs. This explains the huge increase in European soybean meal imports[133].

[127] Tallentire C.W, Leinonen I., Kyriazakis I. 2016. Breeding for efficiency in the broiler chicken. A review. *Agron. Sustain. Dev.* 36: 66. doi:10.1007/s13593-016-0398-2.

[128] Knap P.W., Wang L. 2012. Pig breeding for improved feed efficiency. In: Feed efficiency in swine. Patience J.F. (Ed). Wageningen Academic Publishers, Wageningen, 167-181.

[129] Capper J.L., Cady R.A., Bauman D.E. 2009. The environmental impact of dairy production: 1944 compared with 2007. *J. Anim. Sci*., 87, 2160-2167.

[130] Eurostat, 2010.

[131] 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.

[132] Larue S., Abildtrup J., Schmitt B. 2011. Positive and negative agglomeration externalities: Arbitration in the pig sector. *Spatial Econ. Anal*., 6 (2): 167-183.

Roe B., Irwin E.G., Sharp J.S. 2002. Pigs in space: Modelling the spatial structure of hog production in traditional and non traditional production regions. *Am. J. Agric. Econ*., 84 (2), 259-278.

[133] Galloway J.N., Townsend A.R., Erisman J.W., Bekunda M., Cai Z.C., Freney J.R., Martinelli L.A., Seitzinger S.P., Sutton M.A., 2008. Transformation of the nitrogen cycle: Recent trends, questions, and potential solutions. *Science*, 320, 5878, 889-892.

The intensification of farms and specialization of territories has been accompanied by large decrease in the area of permanent grassland and leguminous crops in favour of annual crops (notably cereals). Grassland acreage has been reduced during the last thirty years by approximately 15 M ha. In the EU-6, these losses are estimated at 7 million ha between 1967 and 2007 (i.e. 30%)[134] although there were large differences in trends between countries (no variation in Luxembourg and UK). At the same time, the cattle population has decreased by 5 million heads due to the intensification of milk production and the quota regime. These developments contributed to reducing methane emissions from the European herd, but have led to a significant losses of C from the soils. During this period crop rotations have been simplified and the use of pesticides have been dramatically increased thus leading to the loss of biodiversity.

2.1.2. The role of the Common Agricultural Policy in shaping current livestock farming systems

The CAP of the first period that ended with the 1992 reform has five priorities: to increase farm productivity, to ensure a fair standard of living for producers, to stabilise markets, to assure availability of supplies, to ensure reasonable consumer prices. It sought to achieve these initially through guaranteed prices, exports refunds and imports levies, and then via direct payments to farmers. Since 1992, successive reforms have led to a significant decoupling[135] (Figure 19) but the sector remains supported by high tariff (customs duties) and imports have to meet non-tariff requirements (customs, veterinary, administrative)[136]. Post 2014, livestock holdings have still benefitted from income support measures with decoupled direct aid, direct greening aid which is subject to compliance and some coupled aid for beef, milk, sheep-goat and protein crops are maintained by 27 MSs[137]. The prices paid to meat producers are still higher than world prices. Livestock farming is the main beneficiary of the aid of the second pillar granted to farms located in disadvantaged areas (50% of the European UAA) and of Agro-Environmental Measures (AEM), to compensate for additional costs linked to an unfavourable location or induced by the respect of additional constraints.

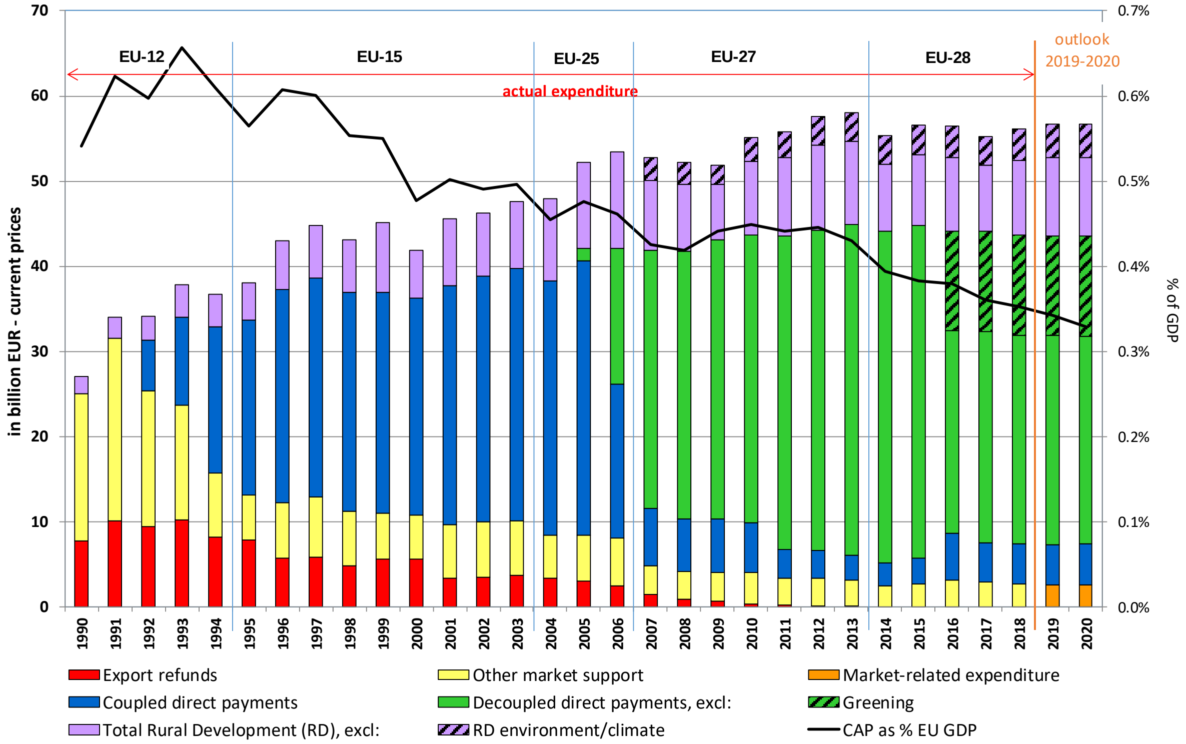
[134] Eurostat, 2009. Agricultural statistics edition 2010: main results 2007-2008: 126 p. See also the FP7-Multisward project.

[135] OCDE 2018. Politiques agricoles: suivi et évaluation 2018. OCDE, Paris, 345 p.

[136] Lawless M., Morgenroth E. L., 2016. The product and sector level impact of a hard Brexit across the EU. Economic and Social Research Institute (ESRI), Dublin, working paper n° 550, 29 p.

[137] European Commission, 2018. Direct payments. European Commission, Brussels, DG Agriculture and Rural Development, 23 p.

Figure 19: Evolution of the CAP budget and its structure between 1990 and 2020, in millions of current euros (left axis) and in percent of gross national product (right axis)



*) 2018: budget amounts; 2019-2020: Annex III Regulation 1307/2013 broken down based on notifications by August 2017 and January 2018, coupled direct payments including POSEI and SAI direct payment component and Annex I Regulation 1305/2013

Source: European Commission, DG AGRI, 2020

Since 1992 the successive reforms expanded the CAP objectives to environment and climate but with limited success. Linking payments to compliance with measures such as the Nitrates Directive (Council Directive 91/676/EEC) has made it possible to slow down the eutrophication process of ecosystems although the Commission has denounced some nonconformities of action plans and brought up legal proceedings with some countries. The Nitrates Directive had not stopped or even had favoured, the concentration and intensification of production systems[138]. Mitigating climate change was not an explicit goal. However, the Nitrates Directive by capping the possibilities of organic fertilization and the direct aids to protein crops since 2014 by increasing their area[139] could have contributed to the reduction of N_2O emissions. The cross-compliance on permanent grassland had led to an annual reduction (in 2016) of 15.8 Mt CO_2eq[140]. The agri-environment-climate measure (AECM) encourage C

[138] Langlais A., Nicourt C., Bourblanc M., Gaigné C., 2014. Livestock farming and nitrogen within the economic and social context. *Advances in Animal Biosciences*, 5, 20–27. DOI: https://doi.org/10.1017/S2040470014000260.

[139] Eurostat, 2019. Performance of the agricultural sector. Eurostat, Statistics explained, ISSN 2443-8219: https://ec.europa.eu/eurostat/statisticsexplained/index.php/Performance_of_the_agricultural_sector.

[140] European commission 2018. Evaluation study of the impact of the CAP on climate change and greenhouse gas emissions. Alliance Environment.

storage practices but aids for disadvantaged areas, by maintaining ruminant systems, is not very compatible with the reduction of GHG emissions. The protection of biodiversity was present in the CAP but positive effects are still severely limited by a low level of ambition[141]. The aid coupled with protein crops, forage legumes or sheep and goats likely contribute to preserving the biodiversity in some regions[142]. The conditionality of greening, maintenance of areas in permanent grasslands and AEM correspond to growing ambitions but to decreasing importance in terms of budget[143].

2.2. Drivers of change for 2030-2050

2.2.1. An environmental emergency coupled with growing health concerns and societal demands

The negative impacts of livestock farming on environment and biodiversity must be reduced. The European Union will probably not be able to meet its commitments made at COP 21[144]. The climate climate change mitigation objectives are ambitious with achieving carbon neutrality in 2050 and a 50% reduction by 2030[145]. Agriculture and in particular livestock are partly responsible for this as they represent an important source of greenhouse gas. The negative effects of agriculture on the water and soil compartments are equally worrying: the recovery of water quality is far from being achieved despite the efforts made and progress remains to be made to reduce losses of N and P and the use of pesticides; soil carbon losses from the conversion of grassland and forest to cropland are important and fast, while the gains generated by the reverse conversion takes several decades and soil erosion affects 13% of the arable land in the EU. Global warming will affect production while the pressures exerted by irrigation on water resources are still significant, especially in the southern MS. The EU adopted in 2011 a new biodiversity strategy where agriculture and forestry play a key role because these two areas cover over 65% of EU area, 50% just for agriculture and a sharp deterioration biodiversity can be observed there[146]. These environmental issues are doubled by health impacts and notably exposure to

---

[141] Pe'er G., Dicks L.V., Visconti P., Arlettaz R., Báldi A., Benton T.G., Collins S., Dieterich M., Gregory R.D., Hartig F., Henle K., 2014. EU agricultural reform fails on biodiversity. *Science*, 344(6188):1090-1092.

[142] Brady M., 2011. The impact of CAP reform on the environment: some regional results. In: Morredu C. (editor), Disaggregated impacts of CAP reforms, Proceedings of an OECD Workshop, OECD Publishing, Paris, pp. 215-234.

[143] Gocht A., Ciaian P., Bielza M., Terres J.M., Röder N., Himics M., Salputra G. 2017. EU-wide economic and environmental impacts of CAP greening with high spatial and farm-type detail. *J. Agric. Economics* 68(3): 651-681.

[144] IPCC, 2018. Global warming of 1.5 °C. IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty: https://www.ipcc.ch/sr15/.

[145] The European Green deal 2019. Communication from the commission to the European parliament, the European council, the council, the european economic and social committee and the committee of the regions. Brussels, 11.12.2019 COM(2019) 640 final.

[146] Commission européenne, 2011. La stratégie de l'UE en matière de biodiversité à l'horizon 2020. Bruxelles, 28 p.

pesticides and Parkinson's disease[147], air pollution exposure with ammonia and micro-particles[148], negative effect of climate change on human health and livelihood either directly (heat waves) or indirectly (water availability, access to food; sea level rise; etc.)[149].

At the same time, one third of the world population is affected by under or over nutrition, as well as "hidden hunger" (micronutrient deficiencies), leading to stunting, avoidable ill-health and premature death which impose huge costs on society (up to USD 3.5 trillion per year)[150]. The Intergovernmental Panel on Climate Change (IPCC) in their most recent report[151] recognized that "Consumption of healthy and sustainable diets presents opportunities for reducing GHG emissions from food systems and improving health outcomes".

The issue of animal welfare is a problematic one and will greatly affect the future of animal farming and its acceptability by people. The collective "sentiment" believes that animal farming is negative for welfare and regardless of the level of care provided in farming systems, close-confinement housing systems appear unnatural to many citizens. Improving the living conditions of animals becomes apriority, we must go beyond the traditional approach which considered welfare on the fringes of the farming system to consider animal welfare at the heart in the design of sustainable farming systems. This concern the respect of the animal integrity with reduction of mutilation practices and the development of practices favourable to the expression of positive mental health conditions of animals. Animal welfare is high in the political agenda and the Commission's Directorate-General for Health and Food Safety announces recently the creation of a working group on labeling relating to the welfare of farm animals and will adopt an ambitious five years program, which will begin with the presentation of a proposal to review EU animal welfare legislation and will continue considering the most effective strategies to better inform consumers about animal welfare.

---

[147] Moisan F., Spinosi J., Delabre L., Gourlet V., Mazurie J.L, Bénatru I., Goldberg M., Weisskopf M.G., Imbernon E., Tzourio C., Elbaz A., 2015. Association of Parkinson's disease and its subtypes with agricultural pesticide exposures in men: a case-control study in France. Environmental Health. *Perspectives,* 123(11): 1123-1129.

Kab S., Spinosi J., Chaperon L., Dugravot A., Singh-Manoux A., Moisan F., Elbaz A., 2017. Agricultural activities and the incidence of Parkinson's disease in the general French population. *Eu. J. Epidemiol.* 32(3): 203-216.

[148] Sutton M.A., Howard C.M., Erisman J.W., Billen G., Bleeker A., Grennfelt P., van Grinsven H., Grizzetti B., 2011. The European Nitrogen Assessment? Cambridge University Press.

[149] Costello A., Abbas M., Allen A., Ball S., Bell S., Bellamy R., Friel S., Groce N., Johnson A., Kett M., Lee M., Levy C., Maslin M., McCoy D., McGuire B., Montgomery H., Napier D., Pagel C., Patel J., de Oliveira J.A., Redclift N., Rees H., Rogger D., Scott J., Stephenson J., Twigg J., Wolff J., Patterson C. 2009. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. *Lancet* 373(9676): 1693-1733.

[150] FAO and WHO. 2019. Sustainable healthy diets – Guiding principles. Rome.

[151] IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [Shukla P.R., Skea J., Calvo Buendia E., Masson-Delmotte V., Pörtner H.O., Roberts D.C., Zhai P., Slade R., Connors S., van Diemen R., Ferrat M., Haughey E., Luz S., Neogi P., Pathak M., Petzold J., Portugal Pereira J., Vyas P., Huntley E., Kissick K., Belkacemi M., Malley J.(eds.)].

A society calling out for agriculture to change. Trend analyses in Europe[152] reveal growing customer expectations and change in attitude toward foodstuff selection in response to these challenges, although the relative importance of criteria sometimes differs among MSs and groups of citizens. Society can influence sustainable food production through the political system, but also more directly through consumer choice.

2.2.2. A reduction in the consumption of meat

The reduction in meat consumption is undoubtedly a driver to consider even if the extent of the phenomenon remains difficult to predict without a precise knowledge of trends, drivers and attitudes in consumption, especially intergenerational differences and stratification within a population and intercultural reasons. Consumers' willingness to reduce their meat consumption was high (72%)[153] and the recommendation of the World Health Organization is a 50/50 balance between animal and plant proteins for a healthy diet while our current Western diets are close to a 65/35 ratio.

New technological foods may also displace livestock products in medium term (i.e. by 2030)[154] but the impacts on meat consumption are difficult to estimate to date for various reasons. It seems that it is the plant based substitutes that can develop and gain market share the fastest.

- **They are still at a pre-commercial stage and scaling up is a big challenge** for some products, notably for in vitro meat and insects. The production of insects will not exceed 1.5 million tonnes or can reach 5 million tonnes in the most optimistic scenario (i.e. less than 2 million tonnes of protein)[155] depending a lot of the evolution of legislation and technology. This will not change in depth the animal feed market which uses 23 million tonnes of proteins for pig and poultry including 13 million tonnes imported soya protein[156]. There are still numerous technological obstacles that have to be overcome to produce in vitro meat as identification of immortal cell lines,

---

[152] https://www.sial-network.com/Get-inspired/The-Future-of-Food/Trends-and-food-around-the-world-what-demand-what-offer

https://www.foodnavigator.com/Article/2019/11/27/Consumer-trends-to-watch-for-in-2020?utm_source=copyright&utm_medium=OnSite&utm_campaign=copyright

Grunert K.G., 2006. Future trends and consumer lifestyles with regard to meat consumption. *Meat Science* 74 , 149–160.

Falguera V., Aliguer N., Falguera M. 2012. An integrated approach to current trends in food consumption: Moving toward functional and organic products? *Food Control* 26, 274e281.

[153] Vanhonacker F., Van Loo E.J., Gellynck X., Verbeke W. 2013. Flemish consumer attitudes towards more sustainable food choices. *Appetite*, 62, 7-16.

[154] Tubbs R., Seba C. 2019. Rethinking Food and Agriculture 2020-2030. The Second Domestication of Plants and Animals, the Disruption of the Cow, and the Collapse of Industrial Livestock Farming. A Rethink Sector Disruption Report.

World Economic Forum, 2019. Meat: the future series, Alternatives proteins. White paper 30p. Geneva, Switzerland.

[155] International Platform of Insects for Food and Feed, 2019; http://ipiff.org/publications-position-papers/.

[156] Dronne Y. 2018. Les matières premières agricoles pour l'alimentation humaine et animale : l'UE et la France. In: Ressources alimentaires pour les animaux d'élevage. Baumont R. (Ed). Dossier, INRA Prod. Anim, 31, 181-200. *Data from FAO, EUROSTAT, FEDIOL et Oil World.*

availability of cost-effective, bovine-serum-free growth medium for cell proliferation and maturation. Due to the lack of fine blood vessels that supply cells with the nutrients and oxygen they need, and the diffusion limits, only a few layers of cells can be produced using currently available culture techniques and producing thicker cuts of meat is a challenge[157]. Intellectual properties, regulatory aspects, labelling issues are also part of the question and a long period is still necessary before in-vitro meat be available at affordable price for the mass market[158].

- **They may not always meet nutritional and sanitary standards.** Manufacturing processes destroy the structure of plant natural fibre and multiply additive and soy products may contain endocrine disruptors. For in vitro meat, serious questions are raised concerning the composition of culture media used in bioreactors. Beyond nutrients (carbohydrates, amino acids, lipids, vitamins ...), growth factors (TGFβ, FGF, IGF) and hormones (insulin, thyroid hormones and growth hormone) are necessary to maintain the viability of cells and allow them to proliferate. These hormones and growth factors are banned in European livestock farming since 2006 and the fate of these molecules in the environment is not known. The sanitary challenge and risk of contamination with virus in insect production is huge and development of insect food allergy cannot be ignored[159].
- **Their environmental benefit is uncertain**. In vitro meat production requires a lot of energy and despite an advantage in the short term by reducing the emissions of methane, this advantage narrows in the long term as CH_4 has a far shorter residence time in the atmosphere than CO_2[160]. The assessment of environmental impact of insects protein production show that environmental footprint and energy consumption is higher than for poultry and pig production and that mealworm meal[161] has a poor environmental performance compared to production of other sources of protein used in animal feed (as soybean or fish meal proteins), the main limitations being resource used to feed insects and consumption of electricity (raising worms, making flour, oil and flour yield). Insect production for food production using wheat bran and other edible plant biomass is less efficient than chicken production and do not show specific advantage apart the animal welfare issue. However, improvements are expected, which should improve the environmental performance.

[157] Bhat Z.F., Kumar S., Fayaz H. 2015. In vitro meat production: Challenges and benefits over conventional meat production. Journal of Integrative Agriculture, 14(2),241–248.

Fraeye I., Kratka M., Vandenburgh H., Thorrez L. 2020. Sensorial and Nutritional Aspects of Cultured Meat in Comparison to Traditional Meat: Much to Be Inferred. Front. Nutr., 7.

[158] Warner R.D., 2019. Review: Analysis of the process and drivers for cellular meat production. *Animal.*, 1-18. Consortium 2019 animal DOI: https://doi.org/10.1017/S1751731119001897.

[159]de Giera S., Verhoeckxa K. 2018. Insect (food) allergy and allergens. Molecular Immunology 100. 82–106

Kung S.J., Fenemore B., Potter P.C. 2011. Anaphylaxis to Mopane worms (Imbrasia belina). Ann. Allergy Asthma Immunol. 106, 538–540.

[160] Lynch J., Pierrehumbert R. 2019. Climate impact of cultured meat and beef cattle. *Frontiers in sustainable food system*, 3, 1-11.

[161] Thevenot A., Rivera J.L., Wilfart A., Maillard F., Hassouna M., Senga-Kiesse T., Le Feon S., Aubin J. 2018. Mealworm meal for animal feed: Environmental assessment and sensitivity analysis to guide future prospects. *J. Cleaner Prod.*, 170: 1260-1267. DOI: https://doi.org/10.1016/j.jclepro.2017.09.054.

- **Consumer reactions are not yet well known** even if 73% of consumers declare their willingness to consume greener meat substitutes. Among them, 45% agreed to consume hybrid meat types (protein mixtures of animal and vegetable origin) and 35% vegetable protein products[162]. In contrast, only 5% reported being ready to consume insect-based protein sources and even less for *in vitro* meat. According to IPIFF, insect for food will remain a niche market because of the reluctance of European consumers due to cultural habits. The question of the acceptability of *in vitro* meat must be asked in particular because of the danger that the diffusion of a product resulting from an innovative but not validated technology and with effects not evaluated on human health could represent[163]. However, at this stage, it is difficult to make any kind of definitive assessment about the eventual acceptance of artificial meat and opinions appeared to be quite diverse[164].

2.2.3. Technological innovations in farming systems

Advances in biotechnologies (genome expression, implementing early programming of animals, mastering microbiomes) will allow more precise selection on traits of socioeconomic interest and have more robust, more adaptable and efficient animals and animal products of higher qualities, control and management of microbial communities to improve health through preventive approaches along the food chain based on microbial ecology. New digital technologies (sensors, robotics, internet of things, "block-chain" ...) provide innovative tools and concepts for animal and system management and phenotyping on large numbers for efficient genomic selection. The continuous and automated processing of a huge quantity of data also offers new possibilities for certification, quality management along the food chain and increased transparency in relations between companies and with consumers with regard to production methods. Innovation in technological processes must improve the nutritional value of plant by-products for animal feed (e.g. improvement of the nutritional value of local meals or the development of a green bio-refinery process to produce protein paste that can be used to feed monogastric animals[165]), offer new opportunities for manure utilisation and development of innovative products from animal carcasses.

Investment in research are required to develop and take advantages of the margins of progress. Co-construction of knowledge and innovations with stakeholders and society is crucial to avoiding resistance to innovation adoption.

[162] Vanhonacker F., Van Loo E.J., Gellynck X., Verbeke W., 2013. Flemish consumer attitudes towards more sustainable food choices. Appetite, 62, 7-16.
[163] Driessen C., Korthals M. 2012. Pig towers and in vitro meat: Disclosing moral worlds by design. Social Studies of Science, 42(6) 797–820.
[164] Verbeke W.A., Rutsaert P., Gaspar R., Seibt B., Fletcher D., Barnett J. 2015. 'Would you eat cultured meat?': Consumers reactions and attitude formation in Belgium, Portugal, and the United Kingdom. Meat Science, 102, 49-58.

Laestadius L.I. 2015. Public Perceptions of the Ethics of in-Vitro Meat: Determining an Appropriate Course of Action. Journal of Agricultural and Environmental Ethics 28(5), 991-1009.

[165] Espagnol S. 2019. Adapting the feed, the animal and the feeding techniques to improve the efficiency and sustainability of monogastric livestock production systems. Life Cycle Analyses of proposed approaches within a sample of production systems. Feed-a-gene, H2020 Eu Project, Delivrable 6.2.

Santamaria-Fernandez M., Uellendahl H., Lübeck L. 2016. ORGANOFINERY: A biorefinery for the production of organic protein rich feed for monogastric animals.

On farm and food chain investments are also required to benefit from these new technologies and new organization. These investments are highly dependent on a vibrant European livestock sector with sufficient critical mass.

3. Improving livestock sustainability

By "improving livestock sustainability" we mean maintaining (or increasing) commodity production while reducing the net environmental impact associated with that production and increasing the ability of the sector to withstand physical or financial shocks. What livestock sustainability means in a specific situation will depend on a range of the factors, but could include: improving price and non-price competitiveness, mitigating and adapting to climate change, enhancing ecosystem services and the improvement of quality of life for the animals and the people working with them. We need to demonstrate how to maximise synergies and avoid trade-offs between those priorities

3.1. The future role of livestock in sustainable agri-food chains

3.1.1. Redesigning the place and role of livestock within agri-food systems

The challenges go far beyond the livestock sector which is too often considered independently of other agricultural sectors. To match economical and societal expectations regarding sustainability and health of our agro-food system, a conversion of the agricultural sector is required that targets nearly every aspect. It requires the deployment of technology and know-how, new business models with new value sharing principles as well as supportive policies and legislation. Some of the disservices are common to animal and plant production; this is the case, for example, of water pollution by excess nitrate and N_2O emission which can be of mineral origin (synthetic nitrogen fertilizers) or organic (animal manure). Others disservices are more specific to plant production as excessive use of herbicides, simplification of crops rotation, loss of soil organic matter (OM). Some others are specific to animal production as animal welfare issue, or enteric methane emissions. Livestock can also provide some valuable services more easily than the cropping sector, such as employment in marginal rural areas, landscape management and habitats preservation with grassland and associated hedges and to some extent soil fertility. Livestock farming is part of the whole agri-food system, it should reduce its own impacts but it is also part of the solution. In a world of finite resources and with sometimes highly degraded ecosystems, adjustments to be performed are major and question the place and role that must keep livestock within agri-food systems which should not exceed the planetary boundaries[166].

The European Green Deal, Farm to Fork Strategy and Biodiversity Strategy[167] proposed ambitious environmental goals for agriculture i.e.: increasing the EU's climate ambition[147], reducing the use of pesticides and antibiotics by 50% and nutrient losses by at least 50% by 2030, restoring ecosystem and biodiversity, developing deforestation free value chains and reaching 25% of organic farming area and 10% of areas with high diversity (agro-ecological infrastructures). There are not yet specific objectives for animal welfare although it is claimed it is another priority. Livestock has huge potential for contributing to these objectives and thus recovering its full legitimacy.

This challenge implies (re)connecting livestock and crop production and provide new responsibilities for the livestock sector to achieve synergies. Circular and sustainable agri-food systems must integrate crop production and animal husbandry with an efficient use of non (or scarcely) renewable resources, which not only produce healthy food at an affordable price, but also eliminate losses by recycling biomass between sectors, reduce gross GHG emission and contribute to remove CO_2 from atmosphere, help maintain the quality of ecosystems, ensure resource security and adaptation to climate change. Such systems have a primary aim to produce food ("Food first")[168] then to maximize the development of various uses of the biomass of plant and animal origin to end-up with the production of bio-energy and to produce other goods and services recognized by society, starting with the storage of carbon in the soil, the preservation of biodiversity and other environmental services (Figure 20). Livestock will play an essential role in such circular agri-food systems. Livestock farming can contribute to closing nutrient cycles by favouring organic fertilizers rather than synthetic fertilizers and by exploiting the ability of animals to recycle into food chain non edible biomass use biomass that is not directly usable in human food[169]. Some opportunities exist to develop more sustainable livestock farming systems and whose roles and services are recognized and appreciated by society.

[166] Rockstrom J., Steffen W., Noone K., Persson A., Chapin F. S., Lambin E., Lenton T.M., Scheffer M., Folke C., Schellnhuber H., Nykvist B., De Wit C.A., Hughes T., van der Leeuw S., Rodhe H., Sorlin S., Snyder P.K., Costanza R., Svedin U., Falkenmark M., Karlberg L., Corell R. W., Fabry V. J., Hansen J., Walker B., Liverman D., Richardson K., Crutzen P., Foley J. 2009. Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society* 14(2): 32. [online]URL:http://www.ecologyandsociety.org/vol14/iss2/art32/.

[167] European Commission, 2020. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. Published 2020-05-20.

European Commission, 2020. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions EU biodiversity strategy for 2030 bringing nature back into our lives. Published 2020-05-20.

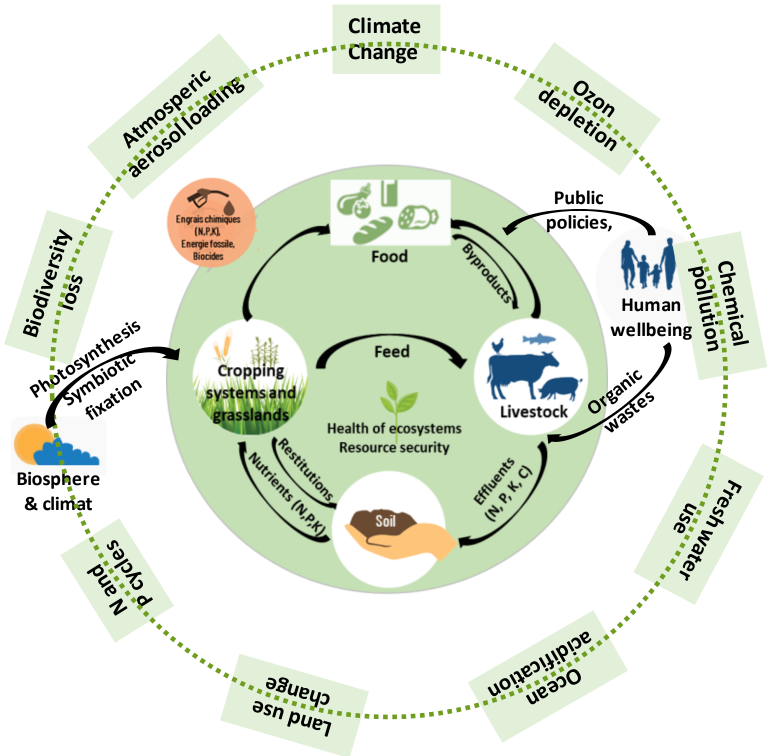
[168] Mathijs E. (chair), Brunori G., Carus M., Griffon M., Last L. (et al), 2015. Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy. A Challenge for Europe. 4th SCAR Foresight Exercise. European Commission. B-1049 Brussels.

[169] HLPE, 2019. Agro-ecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by The High Level Panel of Experts on Food Security and Nutrition. Rome.

De Boer I.J.M., Van Ittersum M.K. 2018. Circularity in agricultural production. Wageningen, Netherlands, Wageningen University & Research. https://www.wur.nl/upload_mm/7/5/5/14119893-7258-45e6-b4d0-e514a8b6316a_Circularity-in-agricultural-production-20122018.pdf.

GHG mitigation is a priority and the Commission wants to achieve C neutrality in 2050 and to increase the EU's greenhouse gas emission reductions target for 2030 to at least 50% compared to 1990[147]. A strategic plan has been produced[170]. Facing this challenge, livestock will have a major role to play by reducing emissions via efficient use of resources, low carbon energy production and soil C sequestration (grassland, agroforestry techniques). However livestock and agricultural production will always result in non-CO_2 GHG emission due to the fact that biological processes are involved.

Figure 20: Role and place of livestock in balanced circular food production within planetary boundaries



3.1.2. Pathways of progress

The sustainability of livestock could be improved through efficiency gains, substitution of high impact inputs with lower impact alternatives or via more fundamental redesign of agricultural systems involving shifts from linear approaches to circular approaches.

- **Increasing efficiency in the use of resource is more important than ever**. Improving biological efficiency can lead to reductions in the physical flows into and out of the production system, and the associated negative impacts that arise from these flows. Efficiency should be considered at the animal/herd level but also at the level of the system considering recycling of biomasses.

[170] Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy COM (2018) 773.

However, increasing efficiency is not sufficient because it does not guarantee the resilience of production systems to climate or health hazards and does not reflect the ability of production systems to restore the quality of ecosystems and secure resources. This is why, it is also important to capture the ability of systems to maintain or even "regenerate" the quality of ecosystems and resources through the development of agro-ecological farming systems.

- **A second option is to the substitution of one input with a lower impact alternative**, for example replacing synthetic N fertiliser with N fixed by legumes or better use of manures.
- **A third option is to identify synergies that can arise from integrating processes**. Exploiting synergies sometimes implies a deeper redesign of the agricultural system and/or the food chain. Agro-ecology is based on strengthening synergies between the components of the production system as well as the spatiotemporal organization of biological cycles to increase biological regulations and the provision of ecosystems services including production of food, restoration of biodiversity and health of ecosystems (including animal health and welfare), increase soil C storage, the reduction of environmental impacts. In addition, the circular economy is exploring possibilities for closing the cycles of biomasses and energy in cross-sectoral and cross-systems process[171]. Agroecology and the circular economy are complementary to produce with less inputs (water, fossil energy, fertilizers and biocides) and close nutrients cycles, the intensity of the link to the soil determining the level of articulation between the levers of agroecology and those of the circular economy.

The inclusion of a wider perimeter considering livestock farming as one element of circular agri-food system within planetary boundaries opens new prospects for progress in addition to tracks already explored. They concern:

- **Rethinking ways of progress in livestock farming systems.** Beyond solving the problems one by one as they emerge it is necessary to develop more holistic approach for designing innovative livestock systems aiming as a priority to be climate smart (i.e. almost carbon neutral and resilient to climate change) and preserving animals welfare and human well-being while reducing the risk of developing antibiotic resistance. The ways of progress are possible at animal level through genetics, nutrition and husbandry practices and at the system level particularly with the management of manures and land use to produce feed.
- **Rethinking the links between livestock farming, plant production and regional dynamics.** The (re) coupling of animals and plants can contribute to an agriculture that facilitates the recycling of nutrients, reduces consumption of fossil energy and chemicals, enhances soil fertility and biodiversity (Figure 19). The scale and the terms of (re) coupling can be highly variable from farm level, exchanges between neighbouring farms to exchange between territories/regions or even the reintroduction of livestock in areas where it has

[171] Dumont B., Fortun-Lamothe L., Jouven M., Thomas M., Tichit M. 2013. Prospects from agro-ecology and industrial ecology for animal production in the 21st century. *Animal,* 7:6,1028–1043.

gone. The (re) coupling is of particular interest in the context of the development of organic farming where livestock farming provides cheap fertilizers and where it can benefit in return from local certified organic food at attractive prices. Specific options include the optimized recovery of effluents and the diversification of rotations with expected benefits on soil fertility, biodiversity, reduced use of pesticides.

- **Rethinking the links between livestock production, food processing and consumption**. The consumers choices and their motivations are various and concerns intrinsic quality of food (safety, nutrition, health) but more and more extrinsic quality such as environmentally friendly production methods, no-GMO food, high standard of livestock health and welfare, local origin, fair incomes for farmers and traceability. Some consumers are prepared to pay more for some of these criteria while others are concerned by affordability. To face demands and the necessity of attaining added value on the export markets, a greater focus on animal-derived food integrity is needed to help European food systems earn consumer trust. Traceability is a key question. The diversity of production systems and products gives resilience to the entire European production sector and may satisfy a wide range of consumer demands.

3.2. Increasing the efficiency of feed conversion by livestock

- The traits associated with feed efficiency are key factors determining the economic productivity, environmental impacts of livestock farming and use of resources. It is therefore dependent on the wider farming system rather than just individual elements, such as specific animal traits. While altering a single part of the system can improve efficiency, care needs to be taken to ensure that any improvements are maintained at the system level.
- Animal efficiency must be studied with alternative feed materials to those used today less in competition with human food. The question is whether or not certain traits that improve food efficiency with diets of excellent nutritional value are retained with lower value rations even though there is currently little evidence that the nature of the diet greatly disrupts animal efficiency ratings[172]. It is also important to check whether the animals most efficient in terms of growth or milk production could be less robust and more sensitive to stressors.
- There are large differences in performance between farms showing that gain of efficiency are still possible by knowledge exchange and encouraging change at farm level using methods and genetics available today. For example the difference between the 20-25% worst and the 20-25% best performing pig farms in the Netherlands are 24 vs 30 raised piglets per sow per year and a feed conversion ratio of 2.87 vs 2.44 kg feed per animal[173].

[172] Montagne L., Loisel F., Le Naou T., Gondret F., Gilbert H., Le Gall M. 2014. Difference in short-term responses to a high-fiber diet in pigs divergently selected for residual feed intake. *J. Anim. Sci*., 92, 1512-1523.

[173] European Feed Technology Center, 2013. Vision and SRIA document 2030: feed for food producing animals. 12 p.

3.2.1. Improving the efficiency of ruminants

The search for efficiency must consider both milk yield and robustness / longevity of the cow to have animals with better balance between milk yield and others production traits than in the past. The efficiency of a dairy or beef herd depends on the performance of each individual animal type (cows, heifers, female calves etc.), and the herd structure (the relative proportions of each animal type within the herd).

- **In dairy systems**, milk yield per lactation, cow fertility rate, the number of lactations per cow and the absence of diseases (mastitis, lameness, subacute acidosis, etc.) are key determinants of efficiency. In the future, fertility and longevity (and associated robustness criteria) will be key issues because increasing the rate of involuntary culling results in inflated replacement costs, which in turn increases the emissions to the environment[30] and the need for feed. At the same time, genetic merit for milk production remain an objective notably because high producing animals always produce more milk than animals with lower genetic potential even in low input systems[174] but the selection on this criterion alone can lead to health issues[175]. Dual purpose breeds may find renewed interest, at least in some regions by making it possible to produce up to 7,000 kg of milk per year mainly with grassland while ensuring a certain stability of income due to the dual milk and meat product.
- **In beef systems**, cow fertility, calf growth rates and precocity are important, and again influenced by genetics, nutrition, physical environment and health status. Calf mortality is a huge issue for efficiency because the loss of one calf is equivalent to the loss of its mother's feed consumption for one year (i.e. 4 to 5 tonnes of feed). In addition, the growth rate of animals finished for beef (and hence their feed efficiency) depends on the age at which they are slaughtered. Beef and dairy systems are highly interdependent so long as the ratio between milk and meat consumption do not evolve. Any increase in milk production per cow means less meat is produced for the same milk production and an increase in suckler beef is required to compensate and this can offset the efficiency gains made via increased milk yield per cow at a global level[176].

[174] Delaby L., Horan B., O'donnovan M., Gallard Y., Peyraud J.L. 2010. Are high genetic merit dairy cows compatible with low input grazing system? Proceeding of the 23th General Meeting of the European Grassland Federation, 13, 928-929.
Berry D., Friggens N., Lucy M. and Roche J. 2016. Milk production and fertility in catlle. *Annual Review of Animal biosciences*, 4, 269-290.

[175] Hardie L.C., VandeHaar M.J., Tempelman R.J., Weigel K.A., Armentano L.E., Wiggans G.R., Veerkamp R.F., de Haas Y., Coffey M.P., Connor E.E., Hanigan M.D., Staples C., Wang Z., Dekkers J.C.M., Spurlock D.M., 2017. The genetic and biological basis of feed efficiency in mid-lactation Holstein dairy cows. J. Dairy Sci., 100, 9061-9075.

[176] Flysjo A., Cederberg C., Henriksson M., Ledgard S., 2012. The interaction between milk and beef production and emissions from land use change critical considerations in life cycle assessment and carbon footprint studies of milk. J. Cleaner Production, 28, 134-142.

3.2.2. Improving the efficiency of non-ruminants

- **In pig production**, recent (since 2005) trends in European pig performance indicate significant increases in sow fertility but limited reductions in feed conversion ratio (FCR)[177]. The slower than predicted improvement in FCR represents a rebound effect – improved genetics have reduced FCR at a given weight but this has also led to increases in weights at slaughter, offsetting the reductions in FCR. The rate of improvement in pig FCR might be lower in the future than in the past because practical barriers (such as the limitations of the production environment) and consumer preferences (e.g. to transgenic manipulation) and animal welfare issues may constrain future improvements in pig performance[178]. However precision feeding is very promising and could reduce nutrient excretion by around 20% for growing animals[179]. It seems that the improvement of feed efficiency has no negative effect on robustness and in particular on the immune system[180]. The mortality rate *in utero* and before weaning is quantitatively important and reducing piglet mortality will contribute to efficiency.
- **In broiler production**, since the beginning of the industrial broiler breeding programmes in the early 1950s, growth rate has been the main selection trait, and improvements in this trait have led to significant improvements in feed efficiency, reducing the emissions intensity, the costs of broiler farming and the price of poultry meat. However, due to biological and physical limits, future improvements in growth rates and feed efficiency are likely to be limited. It seems some limits have been reached as fast-growth rates of the birds and their large breast muscles have led to macroscopic defects in breasts muscles[181]. In addition, changing consumer preferences mean that fast growing broilers may not be the preferred trend in European countries in the future, and

[177] AHDB (2019) Costings and herd performance https://pork.ahdb.org.uk/prices-stats/costings-herd-performance/.

[178] Lamb A., Green R., Bateman I., Broadmeadow M., Bruce T., Burney J., Carey P., Chadwick P., Crane E., Field R., Goulding K, Griffiths H., Hastings A., Kasoar T., Kindred D., Phalan B., Pickett J., Smith P., Wall E., Erasmus K. H., zu Ermgassen J., Balmford A. 2016. The potential for land sparing to offset greenhouse gas emissions from agriculture Nature Climate Change.

Wirsenius S., Azar C., Berndes G. 2010. How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? *Agric. Syst.* 103, 621–638.

IIASA, 2013. Animal Change, Seventh Framework Programme, Theme 2: Food, Agriculture and Fisheries, and Biotechnologies, Deliverable 2.2. (2013). at http://www.animalchange.eu/.

[179] Andretta I., Pomar C., Rivest J., Pomar J., Lovatto A., Radünz Neto J. 2014. The impact of feeding growing–finishing pigs with daily tailored diets using precision feeding techniques on animal performance, nutrient utilization, and body and carcass composition. *J. Anim. Sci*. 2014.92:3925–3936. DOI:https://doi.org/10.2527/jas2014-7643.

[180] Labussière E., Dubois S., Gilbert H., Thibault J.N., Le Floc'h N., Noblet J., van Milgen J. 2015. Effect of inflammation stimulation on energy and nutrient utilization in piglets selected for low and high residual feed intake. *Animal*, 9, 1653-1661.

Young J.M., Dekkers J.C.M. 2012. The genetic and biological basis of residual feed intake as a measure of feed efficiency. In: Feed efficiency in swine. Patience J.F. (Ed). Wageningen Academic Publishers, Wageningen, 153-166.

[181] Petracci M., Soglia F., Madruga M., Carvalho L., Ida E., Est´evez M. 2019. Wooden-Breast, White Striping, and Spaghetti Meat: Causes, Consequences and Consumer Perception of Emerging Broiler Meat. Abnormalities omprehensive. *Rev. Food Sci. Food Safety,* 18, 565-583.

moving towards slower growing birds may lead to reductions in feed efficiency and increases in GHG emissions and nutrient excretion.

- **In egg production**, the changes in hen housing in 2012 resulted in diversification in egg production, with subsequent impacts on GHG emissions and costs of production. The new enriched cages may have resulted in even lower emission intensity compared to the old battery cages[182], while the lower feed efficiency and lower productivity in the alternative systems is likely to have increased the emissions[183]. Over decades, the potential productivity (i.e. the number of eggs per hen per year) has increased considerably as a result of breeding[184] and has led to improvements in feed efficiency and reductions in the GHG emission intensity. However, as productivity is approaching its biological limits, further improvements are likely to be modest. It is estimated that future reductions in emissions achieved through breeding are likely to be less than 10%[185]. Furthermore, the likely future trend of moving away from the cage system towards the less intensive free range for welfare issues and organic systems brings more challenges to the reductions of GHG emissions and nutrient excretion due, in part, to the higher feed conversion ratios in the free range and organic systems[186]. The consequences of these new practices must be evaluated.

3.3. Improving livestock sustainability via substitution

- **The use of resource efficient N-fixing legumes can significantly reduce the amount of synthetic fertiliser applied**, thereby reducing the pre-farm (energy cost of production and distribution and associated CO_2 and N_2O emissions) and on-farm emissions (ammonia, nitrate and N_2O flows) of synthetic nitrogenous fertilisers[187]. It will also contribute to reducing protein imports and associated environmental costs. Fixed quantities of N in the aerial parts can vary from 180 to 200 kg N/ha for the pea and from 150 up to more than 250 kg/ha for the forage legumes as lucerne or red clover[188] with an additional residual effect for the following crop: N fertilization can be reduced from 20 to 60 kg/ha for a wheat that follows a pea, in comparison with a straw

---

[182] Leinonen I., Williams A.G., Kyriazakis I. 2014. The effects of welfare-enhancing system changes on the environmental impacts of broiler and egg production. *Poultry Sci.* 93: 256-266.

[183] Leinonen I., Williams A.G., Wiseman J., Guy J., Kyriazakis, I. 2012. Predicting the environmental impacts of chicken systems in the UK through a Life Cycle Assessment: egg production systems. *Poultry Sci.* 91: 26-40.

[184] Preisinger R. 2018. Innovative layer genetics to handle global challenges in egg production. *Br. Poultry Sci.,* 59: 1-6, DOI: https://doi.org/10.1080/00071668.2018.1401828.

[185] MacLeod M., Leinonen I., Wall E., Houdijk J., Eory V., Burns J., Vosough Ahmadi B., Gomez Barbero M., 2019. Impact of animal breeding on GHG emissions and farm economics, EUR 29844 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-10943-3 (online), doi: 10.2760/731326 (online), JRC117897.

[186] Leinonen I., Williams A.G., Wiseman J., Guy J., Kyriazakis I. 2012. Predicting the environmental impacts of chicken systems in the UK through a Life Cycle Assessment: egg production systems. *Poultry Sci.* 91: 26-40.

[187] Luscher A., Mueller-Harvey I., Soussana J.F., Rees R.M., Peyraud J.L. 2014. Potential of legume-based grassland–livestock systems in Europe: a review. *Grass and Forage Science* 69: 206-228.

[188] Vertès F. 2010. Connaître et maximiser les bénéfices environnementaux liés à l'azote chez les légumineuses, à l'échelle de la culture, de la rotation et de l'exploitation. *Innov. Agronom.* 11, 25-44.

cereals[189]. Grain legumes (e.g. peas or beans) can be readily introduced into arable rotations, however yield is more variable and widespread introduction could lead to a significant increase in the supply of grain legumes and, if not accompanied by increases in demand, decreases in prices. Forages legumes can be introduced into grasslands by sowing clover/grass mixtures or mixed sward which reach similar productivity than fertilized grasses[189]. Nonetheless more attention is needed to the maintenance of the mixed swards than to grass only swards. Forage legumes are well used by animal, lucerne or red clover silage are good companions of maize silage and the interest for the associations of grasses and white clover, or more-complexed associations between several legumes and grasses, is clearly established[190]. Grain legumes such as pea, bean and lupine, may constitute 15 to 20% of the dairy cows rations and can also be used in pig and poultry production if their deficits in certain amino acids are corrected and antinutritional factors are eliminated. Pea can be incorporated in large quantity in the rations for pigs[191].

- **Improved manure management provides additional opportunities to reduce synthetic N fertilizers.** The well-managed return to the soil of livestock manure can allow reducing mineral N fertilizer while contributing to close the nutrient cycles, reducing emission of GHG (CO_2 and N_2O) and fossil energy use associated to mineral N production and increase soil C content. Livestock manure is also a source of P. The amount of nitrogen excreted by animals is almost identical to the amount of mineral nitrogen used on crops at European level[192] and the use of slurry to replace synthetic mineral fertilizers leads to the same production and does not cause additional environmental losses on a 15-year scale[193]. However before using effluents as fertilisers, it is necessary to preserve the nitrogen emitted by animals in order to give it back to crops while losses are sometimes high. Solution to improve use efficiency of manures are described elsewhere (see 1.2.2).

3.4. Developing synergies from integrating processes

Local re-integration of livestock and cropping offers new opportunities to reduce environmental footprint and restore ecosystems functions, soil quality and organic content by the mobilisation of agroecological processes and circular economy. These novel approaches that integrate new livestock farming systems, new cropping schemes fit both for plant-based food and livestock production, with local

[189] Justes E., Nolot J.-M., Raffaillac D., Hauggaard-Nielsen H., Jensen E.S. 2010. Designing and evaluating prototypes of arable cropping systems with legumes aimed at improving N use efficiency in low input farming. In Proceedings of AGRO2010, Congress of the European society for Agronomy, (ESA), 29 August-3 September 2010, Montpellier, France.

[190] Peyraud J.L., Le Gall A., Lüscher A. 2009. Potential food production from forage legume-based-systems in Europe: an overview. *Ir. J. Agric. Food Res*., 48: 115–135.

[191] Dourmad J. Y., Kreuzer M., Pressenda F., Daccord R. 2006. Grain legumes in animal feeding - evaluation of the environmental impact. AEP. Grain legumes and the environment: how to assess benefits and impacts? In: Grain legumes and the environment: how to assess benefits and impact, (ed) European Association for Grain Legume Research. 167-170.

[192] Leip A., Weiss F., Lesschen J.P., Westhoek H. 2014. The nitrogen footprint of food products in the European Union. *J. Agric. Sci*. 152, 20–33. DOI: https://doi.org/10.1017/S0021859613000786.

[193] Leterme P., Morvan T., 2010. Mieux valoriser la ressource dans le cadre de l'intensification écologique. *Les colloques de l'Académie d'Agriculture de France*, 1: 101-118.

biorefinery. Biorefinery approaches have the potential to improve edibility and nutritional value of plants and plant by-products, as well as nitrogen and protein use from manure and green biomass, thereby increasing total plant biomass use and food security.

3.4.1. Livestock as a driver to close nutrients cycles and to reduce pesticide use

There are a range of ways in which livestock can contribute to increasing the "circularity" of the economy. The main approaches are:

- **Using the ability of livestock to utilize a diverse range of biomasses helps to diversify rotations with subsequent advantages.** Poor crop diversification is a source of negative environmental impacts and loss of biodiversity[194]. The diversification of crop rotation also helps to fight against pests and invasive species associated with monocultures while reducing the use of phytosanitary products and enhancing or maintaining biodiversity. The French Ecophyto program shows that the use of pesticides is lower on mixed farming systems (with ruminants) than on specialized cropping systems (the number of treatment per crop and per year averages 2.3 and 3.7 respectively for mix farming and specialized systems)[195]. By strengthening the connection between livestock and cropping systems synergies may also be derived from novel feed sources, nutrients cycling and soils quality. It is also possible to take advantage of a panel of crops (and intercrops) with complementary cultivation requirements and to develop productive cropping systems avoiding specific crops for feed production, ensuring the the protection of soils, particularly over winter to prevent soil erosion and run-off into water courses and to maintain soil organic matter, and anticipating volatility of weather and contributing positively to biodiversity. Finally introduction of trees (agroforestry, edges) in grassland and cropland can be interesting for the storage of C, regulation of N fluxes and for a better adaptation to climate change (shading effect and alternative feed resource for animals during hot periods) even if the effects of trees on crops yield, and harvesting machineries need to be elucidated.

- **Promoting the exchange of effluents between livestock farming regions (farms) and cropping regions (farms)** is very relevant from an environmental point of view[196]. This need to search for the best forms of manure and conditions for transfer and requires advanced bio-refineries to conserve and stabilize nutrient, to produce bio-fertilizers and use them efficiently either as organic N fertilizer (liquid manures, residue of biogas

---

[194] Kleijn D., Sutherland W. J. 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? *J. Applied Ecol.* 40(6): 947-969.

Elts J., Lõhmus A. 2012. What do we lack in agri-environment schemes? The case of farmland birds in Estonia. *Agric. Ecosyst. Env.* 156: 89-93.

[195] Chartier N., Tresch P., Munier-Jolain N., Mischler P. 2015. Utilisation des Produits Phytosanitaires dans les systèmes de Polyculture-élevage et de Grandes Cultures : analyse des données du réseau DEPHY ECOPHYTO. *Renc. Rech. Rum.*, 22, 57-60.

[196] Paillat J.M., Lopez-Ridaura S., Guerrin F., van der Werf H., Morvan T., Leterme P. 2009. Simulation de la faisabilité d'un plan d'épandage de lisier de porc et conséquences sur les émissions gazeuses au stockage et à l'épandage. *J. Rech. Porcine*, 41, 271-276.

production) and/or maximising their role as a source of C for soil with solids forms (solid manure, composts, solid phase) having a slow release of N and to cope with this dual property in a proper way. Another alternative is to study conditions for reintroducing livestock in cropping regions. This requires reducing herds in very dense areas and their redeployment in areas specialized in cereal production. This also requires adapting the proportion of ruminants and non-ruminants to the availability of rough forages/grasslands and concentrate in the territory. These loop-back strategies are potentially very effective but present socio-technical, economic and organizational interlocks: lack of technical reference and know-how, logistics and investment costs, regulatory constraints, social acceptability, difficult match between supply and demand in time and space, organization and governance of these flows, health security of exchanges. These locking points translate into the risk of a mismatch between demand and supply because the mechanisms used in conventional sectors (market, contractualization between actors) are more difficult to apply here since there is neither price reference, neither predictability nor standardization. The terms and forms of management / coordination must adapt to different territorial contexts guided by public authorities.

3.4.2. Livestock to ensure a full use of biomass with no wastes

Livestock can make use of waste streams from other sectors (such as food and drink manufacturing) or can produce biomaterials (such as whey, manure or slaughter by-products) that can be used as inputs in other production. Huge potential lies in the valorisation of organic waste streams, unused residues and new generations of by-products in the food production chain through development of novel and existing technologies.

- **Use of by products and waste stream:** These products can take a wide variety of forms such as second-grade grains, by-products from grain processing and food and drink manufacturing, former foodstuffs (waste food no longer intended for human consumption originating from food manufacturers and retailers), and products from green biotechnologies. By-products from the food industry are actually largely used by livestock even if competition between feed and bio energy production is growing. In addition, feed can be one of several potential uses of a waste stream, and analyses should be undertaken to identify the most sustainable use[197]. There may be scope to increase the use of food waste as feed through processing, but the use of potentially higher risk profile material requires robust assessment to avoid unacceptable threats to human and animal health. Potential land use savings permitted by changing EU legislation to promote the use of food wastes as pig feed are 1.8 million ha (i.e. 20% of agricultural land devoted to pig production)[198].

[197] Leinonen I., Macleod M., Bell J. 2018. Effects of Alternative Uses of Distillery By-Products on the Greenhouse Gas Emissions of Scottish Malt Whisky Production: A System Expansion Approach Sustainability 10(5) DOI: https://doi.org/10.3390/su10051473.

[198] Erasmus K.H.J. zu Ermgassen Z., Phalan B., Green R.E., Balmford A. 2016. Reducing the land use of EU pork production: where there’s swill, there’s a way. *Food Policy* 58, 35–48.

- **Use of new protein sources as feed to recycle non edible biomass in the food chain.** The new feeds include aquatic resources (algae, krill, etc.), earthworms, insects, single cell proteins and products from biorefinery of green biomass as for example extracting grassland juice for pig and using cake for ruminants, to recover nutrients for the feed chain, or to extract bioactive-compounds for the biobased industry. In the short to medium term, insects might be an interesting protein resource for feed because they can be produced in a circular economy from organic residues with relatively high efficiency[199], their nutritional value is high[200] and they can represent 10 % to 15% of feed for chickens and pigs[201]) and even more for fish. Nonetheless the resource will remain too limited to substantially contribute to animal feed market because the expected production would not exceed 8-10% of the total protein resource used for pig and poultry feed (see part 2.2.2)[157, 158] but insects have the potential to provide local solution for poultry (and fish). The development of all these new protein sources requires (i) the development of innovative technologies that ensure sanitary security, eliminate toxic substances, anti-nutritional factors (i.e. mycotoxins) and ensure high feed use efficiency; (ii) the development of life cycle assessments to evaluate the potential of the new technologies from ecological and economic sustainability point of view which in turn raise the limits previously raised concerning LCA approaches (see part 1.6.1) and (iii) guidelines for processes and policies that anticipate social concerns (as some practices may not appeal to society at large as being acceptable) and develop optimal traceability.

In theory, properly functioning markets should allocate resources efficiently, and produce economically optimal levels of circularity, i.e. they should produce a level of waste within a particular process where the marginal social cost (MSC) of reducing waste is equal to the marginal social benefit (MSB) that accrues to society of reducing waste. As we reduce waste, more expensive methods have to be employed, and the MSC increases until we reach a point where reducing waste represents a net cost to society. When trying to make production more circular, the starting point should not be to ask "How do we reduce this waste?" i.e. to assume that increasing circularity will provide a net social benefit. Rather it should be to ask "Is the lack of circularity the result of a market failure?" and, if so, "how can it be corrected?". Nitrogen fertilisers provide an example of how a market failure can reduce circularity. If the costs of the greenhouse gases emitted during fertiliser production are not fully captured in the price, this is likely to make alternative nutrient sources (such as legumes or manures) less financially attractive that they otherwise would be. Such market failures can be corrected, e.g. by the EU Emissions Trading Scheme.

---

[199] Makkar H.P., Tran G., Heuzé V., Ankers P. 2014. State of the art on use of insects as animal feed. Anim. Feed Sci. Techno., 197, 1-33.

[200] Rumpold B.A., Schlüter O.K. 2013. Nutritional composition and safety aspects of edible insects. Mol. Nutr. Food Res., 57, 802-823.

[201] Velkamp T. Bosch G. 2015. Insects: a protein-rich feed ingredient in pig and poultry diet. In Animal Frontiers, 5 (2), 45-50.

3.4.3. Livestock and the production of renewable energy

Energy is one of the main agricultural inputs and leads to significant emissions of CO_2 (and to a lesser extent CH_4 and N_2O) on- and off-farm. The energy use related emission intensity of an agricultural activity is a function of (a) the rate of energy consumption, and (b) the emissions that arise per unit of energy consumed. Substituting fossil fuels with lower carbon alternatives can reduce the latter. This can be achieved via the generation of renewable energy on-farm (e.g. via wind, solar energy with solar panels on the roofs of livestock buildings or anaerobic digestion of manure) or the use of low carbon energy imported into the farm (e.g. via the use of electric tractors powered by low carbon electricity). The methane production potential from the available livestock effluents (24.2 Mt of dry matter) has been quantified in France[202] and would correspond to 45 TWh of primary energy. This corresponds to a value close to the French hydroelectric production which amounts to 54 TWh.

3.5. Livestock and soil C sequestration

Following the completion of the Paris climate change agreement in 2015 there has been renewed interest in the potential of carbon sequestration to deliver greenhouse gas mitigation. Optimistic assessments of soil carbon sequestration (SCS)[203] have suggested that best management practices could sequester between 0.2-0.5 t C/ha, and this has led to the 4 per mil project which proposes that an annual global increase in soil organic carbon (SOC) stocks of 0.4% could make a significant contribution to global greenhouse gas mitigation and would be an essential contribution to meeting the Paris target. Critics of 4 per mil initiative argue that there is limited evidence on which to base assumptions about additional carbon sequestration and also that to achieve the scale of carbon sequestration proposed would require additional nitrogen fertilisation, which would increase nitrous oxide emissions[204]. Specific challenges to SCS include the issues of permanence, the finite capacity of soil carbon storage, the financial resources available to farmers and landowners and policies incentives (see 3.6.2) to introduce new management approaches.

- **Avoiding soil C losses by conversion of grassland to cropland is the first priority** while the change in land use in Europe still leads to C losses, the conversion of grassland to arable land being far from being compensated by the conversion of cropland to grassland and the increase in areas in forest (see 1.2.1). Maintaining grassland area requires livestock.
- **Reducing soil degradation has a large technical abatement potential** as degrading organic soils are an important source of emissions. Three approaches can reduce degradation: protecting intact peatlands, restoring degraded

[202] ADEME, 2016. Mobilisation de la biomasse agricole. État de l'art et analyse prospective. Ademe, collection expertise, 184 p.

[203] Minasny B., Malone B.P., McBratney A.B., Angers D.A., Arrouays D., Chambers A., Chaplot V., Chen Z.S., Cheng K., Das B.S. 2017. Soil carbon 4 per mille. *Geoderma*, 292, 59.

[204] Van Groenigen J.W., Van Kessel C., Hungate B.A., Oenema O., Powlson D.S., Van Groenigen K.J. 2017. Sequestering Soil Organic Carbon: A Nitrogen Dilemma. *Env. Sci. Technol.* 51(9), 4738–4739.

peatlands, and adapting peatland management. Several countries within the EU can be considered 'hotspots' of mitigation potential: Finland, Sweden, Germany, Poland, Estonia and Ireland. Restoring soils and avoiding degradation are likely to displace production. The extent to which this induces indirect emissions depends on the productivity of the land to which the measures are applied. Some organic soils have high yields and displacing production from these areas is likely to displace significant production and emissions. The cost-effectiveness of these measures is highly variable, and depends on the method of peatland restoration, and the opportunity cost of the foregone production.

- **Increasing the soil C sequestration under agricultural land:** Cost-effectiveness analysis done for the UK government indicated significant sequestration could be achieved in the UK by 2035 using the following measures: (i) Optimising the pH of arable and grassland; (ii) Using cover crops; (iii) Introducing grass leys into arable rotations; (iv) Low density agroforestry and (v) Restoration of degraded organic soils. Cost effectiveness of measures such as cover cropping with legumes, optimised fertilisation, organic amendments and reduced till can be positive or negative according to price scenarios[205]. An analysis done in France[206] showed it is in cropland, where the current C stock is the lowest, that resides the highest potential for additional storage (86% of the additional potential), via 5 practices, some of which being dependent on the presence of livestock: use of cover crops (35% of the total potential, moderate cost); Introduction and extension of temporary grassland in crop rotations (13% of total potential, high cost); Agroforestry development (19% of total potential, high cost); Supply of organic compost for a negative cost (slight gain for the farmer); Plantation of hedges (high cost).
- **Increasing C sequestration with forests.** Forests can sequester large amounts of carbon below ground in soil and above ground in wood provided wood produced is not burned. There are three main ways of sequestering carbon in forests: avoiding forest conversion, reforestation and sustainable forest management including management of the risk of fires. The cost-effectiveness varies depending on the revenue from forest products and the income foregone. In general, using anything other than land with a low agricultural potential is likely to make these mitigation measures expensive (although the cost-effectiveness depends on a range of factors, such as growth rates, timber prices, revenue from thinning and the discount rates used[207]), and raises the risk of emissions leakage. However, afforestation and restoration

[205] Sykes A.J., et al. 2019. Characterising the biophysical, economic and social impacts of soil carbon sequestration as a greenhouse gas removal technology Global Change Biology. DOI: https://doi.org/10.1111/gcb.14844 .

[206] Pellerin S., Bamière L., (coord), Launay C., Martin R., Schiavo M., Angers D., Augusto L., Balesdent J., Basile-Doelsch I., Bellassen V., Cardinael R., Cécillon L., Ceschia E., Chenu CL., Constantin J., Darroussin J., Delacote Ph., Delame N., Gastal F., Gilbert D., Graux A.I., Guenet B., Houot S., Klumpp K., Letort E., Litrico I., Martin M., Menasseri S., Mézière D., Morvan T., Mosnier Cl., Estrade J.R., Saint-André L., Sierra J., Thérond O., Viaud V., Grateau R., Le Perchec S., Savini I., Réchauchère O. 2019. *Stocker du carbone dans les sols français, Quel potentiel au regard de l'objectif 4 pour 1000 et à quel coût ?* Synthèse du rapport d'étude, INRA (France), 114 p. https://reseauactionclimat.org/etude-inra-sequestration-carbone/

[207] Eory V., MacLeod M., Topp C.F.E., Rees R.M., Webb J., McVittie A., Wall E., Borthwick F., Watson C., Waterhouse A., Wiltshire J., Bell H., Moran D., Dewhurst R. 2015. Review and update the UK agriculture MACC to assess the abatement potential for the 5th carbon budget period and to 2050 London: CCC.

of degraded forest lands can benefit biodiversity, soils and water resources and increase biomass availability over time.

Implementation of AFOLU C sequestration measures may impact on food security by changing the area cultivated, the yield per unit area or the cost of production. Given the strong relationship between crop yield and gross margin, it is likely that for the most part, cost-effective SCS measures are likely to positively impact yield, though there may exist scenarios in which crop yield is negatively impacted. SCS measures that may reduce the harvested area of a crop are: agroforestry, introducing a perennial phase into rotations, and some soil erosion reduction measures. In general yield improvements should outweigh the impact of harvested area reduction. Afforestation, avoided deforestation and peatland restoration are all likely to reduce the area cultivated. The amount of production and emissions displaced will depend on the yield of the land no longer cultivated.

3.6. Role of public policies, including CAP, to facilitate transitions

The CAP must, more than ever, encourage livestock holdings to minimize the negative effects on the environment and health (GHG emissions, nutrient leakage in the environment, antibiotic use) while promoting the provision of positive environmental services and ensure better working conditions and more peaceful relations between livestock and societies. Given the public health concerns, public policies and/or actors in the supply chains must take up nutrition issues to improve the current situation. Some stakeholders argue for a “Common Agricultural and Food Policy”.

3.6.1. Ensuring agro-ecological transition of the livestock sector

This section 3.6.1 is focussed on ruminants because of their major role in the management of grasslands, agro-ecological infrastructures and maintenance of rural vitality in less favoured regions. Only the animal welfare issue concerns all sectors.

- **Rewarding grasslands for the public goods they provide** (carbon storage, preservation of biodiversity, regulation of nutrient flows, water purification and maintenance of open and diversified landscapes). The economic evaluation of these different services reveals the importance of certain challenges associated with these agro-ecosystems. The cross compliance related to the no-till of permanent grassland must be kept since it has stabilized their area at European level. However, the period allowing classification as permanent grassland should be extended from five years (current situation) to ten years approximately because the duration of 5 years encourages farmers to till young temporary grasslands for having the possibility to change land use in their rotations whereas the services provided are increasing with the age and the floristic diversity[51]. The ecosystems services provided by permanent grassland extensively manages would amount to around € 600/ha/year[208]. It is conceivable to imagine in Eco-Scheme a simple increasing order of support: temporary grassland with a lifespan of less than 5 years (no support) < multispecies (with legumes) temporary grassland less than 5 years < multispecies grassland with legumes more than 5 years old < improved permanent grassland more than 10 years old < natural and semi-natural permanent meadows grown extensively as well as rangelands.

- **Removing coupled aids.** The effectiveness of this aid in terms of supporting agricultural incomes is lower than that of decoupled aid and second pillar aid[209]. This aid also lock farmers into production at the expense of reorientations aimed at better adapting to market developments and consumer expectations, it does not encourage productivity[210] and it is contrary to the necessary reduction of GHG emissions. An eco-scheme on grassland could replace it advantageously and would also increase the legitimacy of supports for farms.
- **Supporting livestock farming in marginal areas for the maintenance of living territories,** often with grassland based extensive ruminant farming must continue to be ensured by means of compensation for the additional costs linked to location and natural handicaps. The rewards must leave the actors free to choose their productive strategy, including reducing herd size and stocking rate. However there is no need to duplicate them with coupled aids partly targeting the same territorial goal and it is more legitimate and more efficient to increase the unit amounts of aids paid in compensation for natural handicaps.
- **Improving animal welfare.** Since animal welfare can be assimilated to a global public good, its improvement requires the intervention of European authorities. Beyond the current regulations that can form the basis of cross compliance, improvement could be encouraged by public supports justified by performance obligations (directly measured on animals). It could be possible to start with supports associating obligations of practices (access to light, access to the outside, reduction in the density of animals, suppression of mutilations or at least complete management of pain, etc.) then gradually increase the indexing of performance requirements. The granting of public aid defined at European level would make it possible to limit the risks of distortion on the part of non-European third countries that are less demanding in terms of animal welfare. It also limits the risks of distortion between MS while allowing private actors to differentiate themselves by opting for a faster implementation of European legislation and / or promoting highest standards by exploiting the positive willingness to pay of some consumers.

[208] Chevassus-au-Louis B., Salles J.M., Bielsa S., Richard D., Martin G., Pujol J.L. 2009. Approche économique de la biodiversité et des services liés aux écosystèmes. Contribution à la décision publique. Centre d'Analyse Stratégique (CAS), 376 p.

[209] Ciaian P., d'Artis K., Gomez y Paloma S. 2013. Income distributional effects of CAP subsidies. *Outlook on Agriculture* 44(1): 19-28.

[210] Rizov M., Pokrivcak J., Ciaian P. 2013. CAP subsidies and productivity of the EU farms. *J. Agric. Economics,* 64(3): 537-557.

3.6.2. Reducing GHG emission

- **Tax livestock emissions under the general European discipline of reducing gross GHG emission.** Setting up a tax on gross emissions of the main determinants of agricultural GHG sources that are mineral N fertilization and livestock would be efficient to foster innovation to reduce the amount payable. Nitrogen sources other than synthetic N fertilizers, i.e. symbiotic fixation and recycling, would be exempted. Emissions could be readily assessed from the mineral fertilizers purchased and the number of animals delivered, based on the associated emission factors used to develop the national inventories[211]. Given the much longer half-life of N_2O than CH_4[24, 25], it might be advisable to tax N_2O more strongly than CH_4 and to encourage better use of mineral and organic fertilizers. The search for economic efficiency across all European production sectors needs to equalize the marginal abatement costs of CO_2-eq per tonne across all productive sectors, not just in agriculture. To avoid distortion of competition and pollution shifts abroad, it would be necessary to tax imports on the same bases or to give back the tax income to the agricultural sector like the Danish did for their pesticide tax whose revenues were used to reduce the agricultural land tax for all farmers. The costs of administering such taxes are low as they apply to operators (distributors of mineral fertilizers, slaughterhouses) who already collect other taxes. Theoretically, the same result could be achieved by subsidizing the reduction of the herd size (beef cow) on the basis of the tonnes of CO_2-eq thus saved[212]. However such subsidy scheme is not sustainable for public finance because the price of animals will increase due to an imbalance between supply and demand for meat which, in turn, will influence the amount of grants to be awarded per animal. In addition, such a subsidy scheme would be contrary to the "polluter pays" principle and therefore to the approach taken in other economic sectors. However, it is a track to explore as it may correspond to an efficient use of EU public funds.
- **Development of "Certified emission reduction units"** could advantageously replace a tax by facilitating on-farm implementation of GHG mitigation projects as technological adoption at the farm level to reduce the emissions might represent the best approach to lowering overall dietary emissions from meat consumption[213]. The principle is a company or a local authority that wants to compensate its GHG production financing the project of (a group of) farmers who want to reduce their emissions on a CO_2-eq basis through a contract for a fixed term (buying C- credits). Emissions are evaluated at the start and end of the contract with a certified diagnostic tool. Compared to a tax, the mechanism allows a much more accurate approach as diagnostic tools can integrate many farms operating parameters (animal feeding, manure

---

[211] 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.

[212] Matthews A., 2019. Why funding a suckler cow reduction scheme in Ireland makes sense. Blog CAP Reform, 27 August 2019, 10 p.

[213] Hyland J. J., Styles D., Jones D. L., Williams A. P. 2016. Improving livestock production efficiencies presents a major opportunity to reduce sectoral greenhouse gas emissions. *Agric. Systems*, 147, 123–131.

management, fertilisation practices, grassland, agroforestry, etc.). It also sends a positive image of livestock farming. Such a project is currently being developed in France for the dairy sector with contracts of 5 years term[214]. Compared to a tax scheme the setting and the functioning of a carbon credit scheme generate much higher transaction costs[215].

3.6.3. Reducing meat consumption by changing consumer behavior

For health reasons it would be useful to reduce the meat consumption of biggest consumers (see 1.5.1) but altering consumer behavior is notoriously difficult and it is even more difficult to target the relevant consumers, for example those with the highest health risks associated to high consumption levels. It is also more legitimate to intervene at the national scales than European scale as there are no spatial nutritional externalities and the costs linked to the adverse effects of food habits on health are supported by the MS.

- **Should meat consumption be taxed for its double burden on environment and health?** As it is often claimed (see for example [216]) on the GHG emission side, a tax on meat consumption ignores the role of nitrogen fertilizers (see above) and thus will be less effective for GHG mitigation while stigmatizing one sector. Simulations show meat taxes are likely to reduce household demand for meat products, resulting in a decrease of GHG emission due to meat consumption. Although reduction will be a function of the level of taxes many simulations show that reduction of GHG emissions related to the entire diet are most often less than 10%[217]. On the health side, the positive impact will be maximised if the revenue from the tax is used to subsidize the consumption of fruits and vegetables[218] but then the C-footprint of the diet will be only marginally reduced (see 1.6.2). In addition red meat will be the most taxed[218] and this would encourage pig and chicken production which would increase competition with humans for feed (see 1.2.4) and could increase environmental loses of N with intensive systems and thus partly shifts the problem. There is also the potential danger that a tax on meat encourages people to switch to cheapest, less healthy processed meats or others alternative highly processed plant based foods. By redistributing the tax proceeds to fruits

---

[214] https://france-carbon-agri.fr/

[215] Stavins R.N. 1995. Transaction costs and tradeable permits. Journal of environmental economics and management, 29(2), pp.133-148.

[216] True Animal Protein Price Coalition, 2020. Aligning food pricing policies with the European Green Deal: True Pricing of meat and dairy in Europe, including CO2 costs. A Discussion Paper. https://drive.google.com/file/d/1Nq2aese3kYTtWZAVP0LQGAc_ci3ZC7Ax/view.

[217] Doro E., Réquillart V. 2018. Sustainable diets: are nutritional objectives and low-carbon-emission objectives compatible? Toulouse School of Economics (TSE) Working Papers 18-913, 46 p.
Sall S., Gren I.G. 2015. Effects of an environmental tax on meat and dairy consumption in Sweden. Food Policy 55 (2015) 41–53.
Chalmers N.G., Revoredo C., Shackley S. 2016. Socioeconomic Effects of Reducing Household Carbon Footprints Through Meat Consumption Taxes. *J. Food Products Marketting,* 22, 258-277.

[218] Wirsenius S., Hedenus F., Mohlin K. 2010. Greenhouse gas taxes on animal food products: Rationale, tax scheme and climate mitigation effects. *Climatic Change*, 108(1–2), 159–184.

and vegetables and/or to notably to help the poorest households, the negative impacts for livestock farmers can no longer be offset.

- **Other ways making progress.** Because consumers are increasingly aware of the environmental impact of the food they consume, carbon labelling of agricultural and processed products can be influential in helping them to make more informed choices[219] even if such voluntary approach cannot reach the optimal pollution abatement since climate mitigation is a public good[220]. It should be remembered that carbon labelling assesses only one aspect of sustainability and this may introduce confusion for consumers. Carbon labelling may allow private actors to differentiate themselves by opting for less emitting systems. Many MSs have set up information campaigns as part of their nutrition policies. The impact on consumption is positive but of limited magnitude. Several intervention experiments (such as facilitating the choice of the vegetarian menu in a restaurant) have shown (limited) effects.

3.7. Some trade-offs and synergies in managing the livestock sector

Tensions may appear between different objectives and this requires the development of an evidence based and balanced vision that counteracts the simplistic solutions that are sometime proposed.

3.7.1. Size and composition of livestock population

Think twice before promoting a sharp reduction of the livestock sector. Faced with the environmental impacts of livestock, it is often suggested that ruminant numbers should be reduced significantly. While this would provide some benefits (e.g. reducing GHG emissions), the following points should be borne in mind.

- Ruminants maintain marginal land and harvest almost 4.5 billion tonnes[221] of biomass whose mechanical harvesting is rarely technically possible and in any case would emit CO_2 from fossil energy use. Large reduction in ruminant populations would induce land use change that could have some unexpected negative effects: abandonment of grassland that would cease to be grazed and that are species-rich could lead to methane production by decomposition of the vegetation and shrubs/forests development will decrease biodiversity[60, 61] and could increase the risk of fire in the long term. Forest needs to be maintained by creating open spaces through pastoralism in a natural and non-binding way.
- We also need to avoid large reductions in EU animal production as such reductions are likely to simply displace production (and the associated impacts)

[219] Hylanda J.J., Henchiona M., McCarthy M., McCarthy S.N. 2017. The role of meat in strategies to achieve a sustainable diet lower in greenhouse gas emissions: A review. *Meat Science* 132 (2017) 189–195. DOI: http://dx.doi.org/10.1016/j.meatsci.2017.04.014.

[220] Kotchen M.J. 2006. Green markets and private provision of public goods. *J. Political Economy*, 114, 816-834.

[221] INRA 2020. Etude Agriculture Européenne.

to other regions. This may lead to a reduction in the impacts of livestock production within the EU (depending on the economic activity that replaces livestock production) but this will be offset by increases in the regions where production is displaced to (which may be regions where livestock production is less efficient and/or has lower animal welfare standards). The challenge is therefore to find ways of improving the sustainability of EU livestock without large scale reductions in production, particularly where such decreases are likely to lead to net increases in impacts.

The balance to be found between the population of ruminants and non-ruminants is more subtle to reason than is often claimed. Most LCA studies show that industrial pig and poultry farming systems are much more efficient ways of producing meat than ruminants and therefore suggest reductions in the ruminant population. But this ignores that ruminants provide other important environmental services[222]. Also dairy cows can be very efficient to provide edible protein in milk and meat (see 1.2.4).

3.7.2. Managing the ancillary effects of greenhouse gas mitigation

Reducing GHG emissions is likely to be an increasingly important driver of agriculture, whether expressed via (public and private sector) policy, or consumer purchasing decisions. However, it is important that the ancillary effects of mitigation are not forgotten in the drive to reduce GHG emissions.

Mitigation measures can have a wide range of (positive and negative) ancillary effects on the environment, economy and society. Twenty impacts of three different types were identified for twelve mitigations measures (Table 2) [223]: *direct impacts* (e.g. changes in physical flows of NH_3, NOx, PM, nitrogen and phosphorous); *intermediate impacts* (on soil quality, flood regulation, biodiversity and resource efficiency) and *endpoint impacts* (human health and social and cultural wellbeing). Most of the effects were neutral or positive, with only a small number of negative impacts (from anaerobic digestion and peatland restoration). Variable effects were common, implying the need for tailored implementation to maximise the benefits while reducing the adverse impacts. The positive effects on air quality, water quality, resource efficiency and human health suggest that integrated approaches in these policy areas could be used to promote co-benefits. Further research is required regarding the impacts on household income, consumer and producer surplus, employment and culture, where the evidence was weakest.

[222] Poux X., Aubert P.M., 2018. An agroecological Europe in 2050: multifunctional agriculture for healthy eating Findings from the Ten Years For Agroecology (TYFA) modelling exercise. Iddri-AScA, Study n°09/18, Paris France, 78p. https://www.soilassociation.org/iddri-report-ten-years-for-agroecology-in-europe/.

[223] Eory V., Bapasola A., Bealey B., Boyd I., Campbell J., Cole L., Glen K., Allan G., Kay A., MacLeod M., Moran D., Moxley J., Rees B., Sherrington C., Topp K., Watson Ch. 2017. Evidence review of the potential wider impacts of climate change mitigation options: Agriculture, forestry, land use and waste sectors Edinburgh: Scottish Government.

Table 2: Summary of the ancillary impacts of 12 GHG mitigation measures

		WI1	WI2	WI3	WI4	WI5	WI6	WI7	WI8	WI9	WI10	WI11	WI12	WI13	WI14	WI15	WI16	WI17	WI18	WI19	WI20
		Air quality: NH3	Air quality: NOx	Air quality: PM	Air quality: other	Water quality: N leaching	Water quality: P	Water quality: other	Soil quality	Flood mgmt, water use	Land cover and land use	Biodiversity	Animal health and welfare	Crop health	Household income	Consumer and producer surplus	Employment	Resource efficiency	Human health	Social impacts	Cultural impacts
MO1	On-farm renewables	0	+	+	+	0	0	0	+/-	0	-	0/-	0	0	+	+/-	+	+	+/-	+	0
MO2	Precision farming	+	+	+	+	+	+	+	+	+	0	+	+/-	+	+	+	-	+	+	+/-	0
MO3	Optimal soil pH	+/-	0	0	0	+	+	+	+	+/-	0	+/-	+	+	+	+	0	0	+	0	0
MO4	Anaerobic digesters	-/0	-	-	0	+/-	-	0	+/-	0	0	0	0	0	+	+	+	++	+/-	+	0
MO5	Agroforestry	+	+	+	0	+	+	+	+	+	+	+	+	+	0	0	0	0	+	0	+
MO6	More legumes	+	+	+	0	-	0	0	+	0	+	+	0	+	0	0	0	+	0	0	0
MO7	Optimal mineral N use	+	+	+	0	+	+	0	0	0	0	0	0	0	0	0	0	0	+	0	0
MO8	Manure storage and application	++	0	+	+/-	+	+	+	+/-	0	0	0	+	0	+/-	0	+	+/-	+/-	0	0
MO9	Livestock health	+	0	0	0	+	+	-	0	0	0	-	+/-	0	0	0	0	+	+/-	0	0
MO10	Reduced livestock product consumption	+	0	0	0	+	+	-	+/-	+/-	+	+/-	+/-	0	+/-	+/-	+/-	+	++	+/-	+/-
MO11	Afforestation	++	++	++	+	+	0	+/-	+/-	++	+	+/-	-	0	+/-	+/-	+/-	+	+	+	+/-
MO12	Peatland restoration	0	0	+	0	-	-	+/-	++	+/-	+/-	++	+	-	+/-	0	0	0	+/-	+	+/-

Legend	
++	Strong positive effect
+	Positive effect
0	No siginificant effect
+/-	Variable effect
-	Negative effect
--	Strong negative effect
	Highly uncertain effect
	Uncertain effect
	Robust effect

Source: Eory et al, 2017[224]

3.7.3. Improving animal welfare in the direction requested by the society

Improving of animal welfare is likely to remain an important driver for the livestock farming systems. The consequences of animal welfare improvement on production costs, animal health and environment should be assessed. These improvements can relate to the improvement, sometimes very significant (for example giving outside access to the animals), of the rearing conditions within existing systems but also in the reconfiguration of the systems, even of the chains, to tackle systems producing low value animals which will no longer be acceptable for a large majority of citizens.

Practices seeking to improve animal welfare in current systems (suppressing mutilation practices and fear and favouring positive emotions with the expression of the species natural behaviours) causes variable effects[225]. The production cost and the workload for farmers are most often increased. Beyond production costs increase, improving animal welfare will require investments, notably for new

[224] Eory V., Bapasola A., Bealey B., Boyd I., Campbell J., Cole L., Glen K., Allan G., Kay A., MacLeod M., Moran D., Moxley J., Rees B., Sherrington C., Topp K., Watson Ch. 2017. Evidence review of the potential wider impacts of climate change mitigation options: Agriculture, forestry, land use and waste sectors Edinburgh: Scottish Government.

[225] Guyomard H., Huyghe Ch., Peyraud J.L., Boiffin J., Coudurier B., Jeuland F., Urruty N. 2016. Les pratiques agricoles à la loupe: vers des agricultures multiperformantes. Eq QUAE.

livestock buildings. The effects on the environment are more variable. For example, the development of a pig or dairy cow building on straw instead of grating will increase N_2O emissions[226]. Similarly, the increase in the area available per animal for the expression of natural behaviour will increase emissions per kg of product. On the other hand, the suppression of castration of pigs reduces emission of GHG, ammonia and nitrates because whole males are more efficient. Systems producing low value animals (which are slaughtered immediately after birth) must be reconsidered either through technological innovation (e.g. sexing embryos in eggs) and/or by reconsidering the organisation of the entire production chain, perhaps by creating new products/markets. One of the major drawbacks is a loss of competitiveness at least in a first step. Reduced lifespan of reproductive female (e.g. dairy cows, hens) is another issue for the future and increasing longevity will become an objective. This strategy has some positive effects on other performances in the case of dairy systems but not in the case of egg production.

Table 3: Summary of the impacts of 8 measures aiming to improve animal welfare in current systems

Practices for improving animal welfare	Production costs	Fossil energy consumption	Soil OM content	GHG emissions	Nitrate emission	Ammonia emission	Use of medications	Workload
Use litter buildings straw in pig farming	-	-	+	-	=	+/-	=/-	-
Use litter buildings straw in dairy farming	-	-	+	-	=/+	+/-	=	-
Give outside access	-	-	+	-	-	+	+/-	=/-
Use of air cleaner (pig and poultry)	-	-	=	=	=	+	=	=
Suppression of castration of pigs	=	=	=	+	+	+	=	+
Suppression of dehorning	-	=	=	=	=	=	=/-	+/-
Increase in the area available per animal	=/-	-	=	=/+	=	-	=/+	-
Enrichment of the living environment	=	=	=	=	=	=	=	=/-
Increasing longevity of dairy cows	+/-	+	+	+	+	+	+/-	+

The indicators are evaluated using a five-level scale: strongly negative (-), neutral or negative according to the situations (=/-), neutral (0), neutral or positive (0/+) according to the situations, strongly positive (+) and uncertain (+/-) according to the situations.

Source: Adapted from Guyomard et al., 2016 and Peyraud, unpublished[225]

Health and welfare are closely related. Diseases related to physiological imbalances, with an infectious component or not, are very dependent on farming practices and, in this sense, are in strong interaction with animal welfare. Infectious diseases linked to exposure to pathogens is a cause of major trade-off with welfare. Biosecurity measures constraining farming practices (e.g. avian influenza) could negatively affect animal welfare and conversely, giving outside access to improve animal welfare could increase some risk of contact with

[226] Rigolot C., Espagnol S., Robin P., Hassouna M., Belline F., Paillat J.M., Dourmad J.Y. 2010. Modelling of manure production by pigs and NH2, NO2 and CH4 emissions. Part II. Effect of animal housing, manure storage and treatment practices. *Animal*, 4 (8), 1413-1424.

pathogens agents, parasites and wild fauna and development of infectious diseases. African swine fever makes it very difficult to maintain pigs outdoors, Influenza is also a big issue for free range poultry. Outdoor rearing also expose livestock to predation.

3.7.4. Reconnecting plant and livestock sector to rejuvenate agriculture

Reinvented complementarities between animal husbandry and crops offer new possibilities to reduce the negative effects of agricultural production. However the practices should be carefully chosen and combined to maximise benefits and limit some negative effects (table 4).

Table 4: Summary of the impacts of some measures for reconnecting livestock and crop sectors for a rejuvenated agriculture

	Production costs	Fossil energy consumption	Soil OM content	GHG emissions	Nitrate emission	Ammonia emission	Pesticide reduction	Biodiversity	Workload
Land use									
Diversify crop rotations	+/-	+/-	=/+	+/-	=/+	+/-	+	+	=/-
Introduce legumes (grains and forages) in rotation	=/+	=	+	+	=/+	+	=/+	+	-/=
Increase the proportion of grassland area	+	=/+	+	=/+	=/+	+	+	=/+	+/-
Develop agroforestry	+	=	+	+	+	+	=/+	+	+/-
Reintroduction of livestock in territories specializer in crop production	-	+	+	+/-	+	+/-	+	+	-
Reduction of livestock in territories specialized in intensive animal production	-	+	-	+	+	+	=/-	+/-	+
Fertilisation management									
Replace mineral fertilizers by manure	=/+	+/-	+	+/-	=	-	=	=	-
Develop precision fertilisation (organic, mineral)	+	=/-	=	+	+	+	=	=	=
Develop anaerobic digestion of effluents	-	+	=/-	+	=/-	=/-	=	=	-
Develop manure composting	-	=/-	+	=/-	+	-	=	=	-
Produce standardized fertilizers from manure	=/+	+	=	+	=/+	+	=	=	+
Feeding and breeding management									
Use various waste streams and by-products	+	=	=	+/-	=/+	=/+	=	=	+
Improve forage quality	=/+	=/-	=	+	=	=	=	=	=/-
Use more efficient animal able to produce from a diversity of plant based products	+	+	+	+	+	+	+/-	=	=/+
Use more robust animal	+	=	=	=/+	=	=	(+)	=	+

Source: Adapted from Guyomard et al., 2016 and Peyraud, unpublished[225]

The practices of feed production can have overall very positive effects both on biodiversity and the limitation of the use of pesticides. Valorising the symbiotic nitrogen fixation by legumes dramatically reduce emissions to the environment and allow reduction in production costs, at least if yields are not severely penalized compared to cereals (which is often the case). The choice of the most appropriate method of manure management must be considered according to the objectives because trade-offs may appear, at least if the methods are not well mastered. For example, if composting is very favourable for increasing the organic matter content of soils, its practice can lead to significant losses of ammonia. Conversely, biogas residue is a nitrogen fertilizer with very labile forms of nitrogen which can lead to the spreading nitrate leaching. Using various waste streams as animal feed enables the recycling of non-human edible biomass but the energy cost and GHG emission could be quite variable and research is needed to optimise the processes.

4. Conclusion

Actual global food production is responsible for 21-37% of global greenhouse gas emissions[227], consumes large amounts of natural resources and contribute to the loss of biodiversity. While livestock farming is a major contributor, much can be done to reduce its negative impacts, including the use of agro-ecological approaches, technology and increased circularity. The Farm-to-Fork strategy[228] opens the way towards a rejuvenated agriculture that stays within planetary boundaries. The goal is to arrive at a low carbon, resource efficient agri-food system that provides a wide range of environmental goods and services (such as healthy soils, biodiversity and an attractive landscape).

4.1. Think twice: maintain a broad vision of livestock farming

It is not possible to address the questions of agri-food systems sustainability without a systemic vision of the consequences of each proposal. There is a scientific consensus for more healthy diets partly rebalanced toward higher consumption of fruits and vegetables, less proteins of animal origin and less sugar. A reduction in EU livestock production is often proposed as a way of simultaneously tackling environmental and dietary issues. Even if reduction in the volume of production of some commodities may be appropriate, we should be careful to avoid unintended negative effects on other aspects of sustainability. By focusing on the cost and impact of producing plant-based food versus animal-based food, the debate is over-simplified and tends to ignore major trade-offs and synergies.

- **It is important to avoid simply displacing production (and the associated impacts) from the EU to other parts of the world.** In many cases, the EU has relatively efficient livestock production, so simply reducing

[227] Mbow C., Rosenzweig C., Tubiello F., Benton T., Herrero M., Pradhan P., Xu Y. 2019. Food security. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security and greenhouse gas fluxes in terrestrial ecosystems. [Shukla P.R., Skea J., Calvo Buendia E., Masson-Delmotte V., Pörtner H.O., Roberts D.C., Zhai P., Slade ., Connors S., van Diemen R., Ferrat M., Haughey E., Luz S., Neogi S., Pathak M., Petzold J., Portugal Pereira J., Vyas P., Huntley E., Kissick K., Belkacemi M., Malley J., (eds.)]. IPCC. Retrieved from: https://www.ipcc.ch/srccl/chapter/chapter-5/.

[228] https://ec.europa.eu/food/farm2fork_en.

European production while the world where demand for livestock products is increasing, may lead to net increases in environmental impact (see 1.2.1).

- **Advocating a reduction of animal production will not necessarily lead to more sustainable agri-food chains**. Different production systems (e.g. intensive vs extensive) have quite different positive and negative environmental performances. In addition, the livestock sector contributes substantially to the overall European economy (see 1.1.1), and is of crucial economic as well as socio-cultural importance for many European regions (see 1.3). Any radical transformation of the EU agri-food system therefore requires a holistic vision of the potential consequences.

- **The net environmental impacts of reducing livestock will depend on the subsequent land use change.** Conversion of pastures to arable crops could lead to soil carbon losses and increased pesticides use, while conversion of pasture to woodland will provide benefits in terms of carbon storage, but may impact on rural vitality or increase the risks of wildfires. Agroecological approaches that integrate more closely crops and livestock and maximize the ability of livestock to use non-human-edible biomass for feed may provide scope for reducing pesticides and synthetic fertilizers use while maintaining food production and ensuring the preservation of natural capital (soil fertility, biodiversity) in the long term.

- **Diets with more fruits and vegetables and less livestock products do not necessarily have a significantly lower C-footprint** (see 1.6.2) and some proposed low C diets deviate considerably from the usual food preferences, raising questions about their social and cultural acceptability.

4.2. Providing a new ambition for the livestock sector

We should move away from simplistic plant vs animal or extensive vs intensive positions to promoting systems well adapted to the diversity of European contexts and seeking to maximising synergies between sectors. It is clear that some countries will have difficulties to move back to extensive and grassland based systems while some others have more open choices for the future. In addition, many consumers are still looking for cheap food thus putting pressure on prices and productivity while healthy diets will be a prominent demand. In this new context:

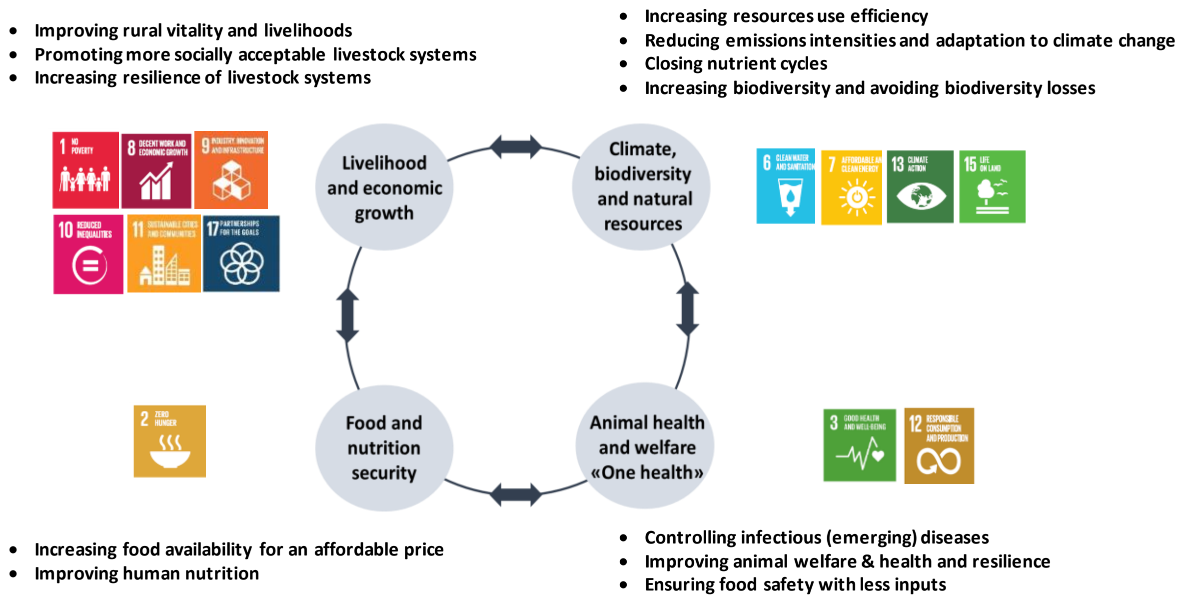
- **Livestock is essential because animals are recyclers by nature*.*** Livestock can contribute to a more efficient agriculture by utilising non-edible biomass and by providing organic fertilizers.

- **Livestock farming is also more than only food production** and contributes to many of the sustainable developments goals[229]. We need to strengthen these roles and to better define the conditions under which livestock make a key

[229] FAO 2018. World Livestock: transforming the livestock sector through the Sustainable Development Goals. Rome. 222 pp. Licence CC BY-NC-SA 3.0 IGO.

contribution. The question should not be "How can we reduce livestock production?" but rather "How can we increase the net social benefit of livestock, while ensuring the costs are distributed equitably?". In all cases we should remember that maintaining the competitiveness of the sector is essential.

Figure 21: The four domains and twelve main issues of improvement for European livestock farming systems



Source: adapted from GFA, 2018[230]

To fulfil its roles, livestock systems should evolve to provide a range of goods and services, rather than be guided by the single goal of commodity production. We summarize the main challenges facing the European livestock in four interdependent sustainability domains (Figure 21) in line with those borrowed from Global Forum on Agriculture (GFA) of 2018[230]. By achieving progress in these domains, the livestock sector will contribute positively to the circular agri-food systems as shown in Figure 20 and to the main ambitions of the European Green Deal, the Farm to Fork Strategy and Biodiversity Strategy[169], thus recovering its full legitimacy.

4.3. Livestock is not only a problem, it is part of the solution

Climate, health and welfare should be placed at the heart of innovation for the livestock farming system of tomorrow. There are many ways to progress (see 3.2, 3.3 and 3.4) including, in order of difficulty of implementation: increasing productive efficiency, substitution of inputs with lower impact alternatives and the development of agroecological practices based on the mobilization of biological processes and circularity that often require a redesign of

[230] https://www.gffa-berlin.de/en/gffa-kommunique-2018/

the systems (Table 5). The use of new technologies (biotechnologies such as genomics, epigenetics, microbiota; digital technologies; innovative biorefineries) and new governance to ensure business continuity so that employment is not at risk will contribute to the transition. Migration to more sustainable products and processes will need to be encouraged by public policies and be rewarded, be visible and get economic appreciation. To reach the objective, most of these approaches have to be mobilized simultaneously. Table 5 provides some examples of innovative approaches presented in this report (see 1.2, 1.3 and 1.4). They are win-win practises in that sense that when they contribute substantially to one objective (e.g. climate mitigation) they have also benefits or at least no strong negative effects on some others objectives (i.e. biodiversity, water quality, etc.).

Table 5: Some examples of practices for improving livestock farming systems

	Efficiency of herds	Substitution	Agro-Ecology	Circular economy
Increasing resources use efficiency	• Animal efficiency • Feeding strategies, feed additives • Herd management : less mortality, lifespan of reproductive females,	• Reducing mineral N application • Take full account of manure N and symbiotic N from legumes	• Diversification of crop rotation for new plant protein sources • More robust animals	• New protein sources derived from wastes (biomass refinement, use of insects, etc.)
Reducing emissions	• Breeding for lower methanogenesis • Breeding for increased efficiency • Feeding strategies including use of methanogen inhibitor • Herd management: less mortality, lifespan of reproductive females	• Use of legumes and manure instead of mineral N fertilizer • Replace feeds associated with land use change with alternatives • Replacing fossil fuel with renewable energy	• Diversification of crop rotation • Manure storage and application • Grassland and hedges development • Soil C sequestration practices • Soil restauration practices • Agroforestry	• Manures transfer between farms and regions • Anaerobic digestion of manure
Closing nutrient cycles	• Breeding for increased efficiency • Precision feeding • Use of feed additive	• Use of legumes and manure instead of mineral N and P fertilizer	• Diversification of crop rotation • Grassland and hedges • Manure storage and application • Soil C sequestration practices • Mix farming systems	• Manure refinement • Reintroduction of livestock in cropping regions • Use of coproduct, waste streams and new protein sources as feed • New value of animal by products
Increasing biodiversity		• Use of legumes	• Crop diversification • Grassland and hedges development • Development of Agroforestry • Use of local breeds	• Integration of crop and livestock at territorial level • Use the ability of livestock to utilize a diverse range of biomasses
Controlling infectious diseases			• More robust animals • Integrated and preventive management of microbial ecosystems	
Improving animal welfare & health	• Prevention of production diseases such as lameness and mastitis	• Vaccines and plant secondary compounds instead of antimicrobials	• Animal robustness and adaptability • Suppression of painful practices • Improvement of living environment for expression of natural behaviour • Integrated preventive management of animal health	
Ensuring food safety with less inputs		• Vaccines and plant secondary compounds instead of antimicrobials • Use of legumes	• Improved animal robustness • Integrated and preventive management of animal health	
Increasing food availability	• Breeding for efficiency		• Develop new copping systems	• Use the ability of livestock to utilize a diverse range of biomasses

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service: – by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls), – at the following standard number: +32 22999696, or – by email via: https://europa.eu/european-union/contact_en

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU publications

You can download or order free and priced EU publications from: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1952 in all the official language versions, go to EUR-Lex at: http://eur-lex.europa.eu

Open data from the EU

The EU Open Data Portal (http://data.europa.eu/euodp/en) provides access to datasets from the EU. Data can be downloaded and reused for free, for both commercial and non-commercial purposes.

KF-02-20-525-EN-N

Publications Office
of the European Union

doi: 10.2762/3440

ISBN: 978-92-76-20624-8