Study on

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

Final report

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

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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.

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[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.

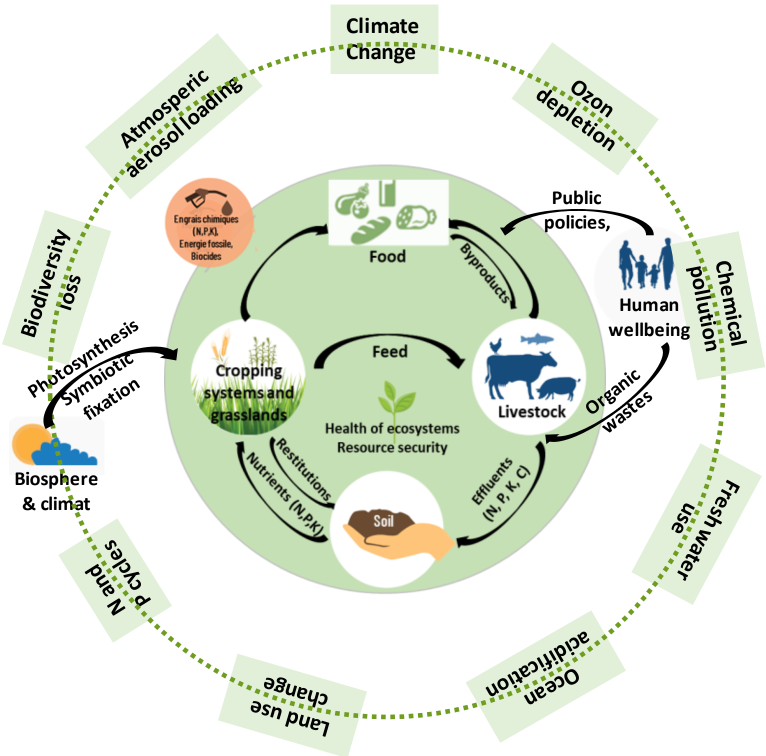
[168] Mathijs E. (chair), Brunori G., Carus M., Griffon M., Last L. (et al), 2015. Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy. A Challenge for Europe. 4th SCAR Foresight Exercise. European Commission. B-1049 Brussels.

[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

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[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.

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