What is the Safe Operating Space for EU livestock?

2018

About the RISE Foundation

The Rural Investment Support for Europe (RISE) Foundation is an independent foundation which strives to support a sustainable and internationally competitive rural economy across Europe, looking for ways to preserve the European countryside, its environment and biodiversity, and its cultural heritage and traditions. It works as a think tank, bringing together experts to address key environmental/ agricultural challenges in Europe and develops high quality accessible research reports with clear recommendations for policy makers. It draws on its extensive network of rural stakeholders to highlight innovative practises developed at the farm level and provides a platform for debate on issues that affect rural communities.

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The RISE Foundation

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Abbreviations

AMR	Antimicrobial Resistance
CAP	Common Agricultural Policy
CH_4	Methane
CO_2	Carbon dioxide
EC	European Commission
EEA	European Environment Agency
EMA	European Medicines Agency
EU	European Union
EU27	Member States after the enlargement on 1/1/2007
EU28	Member States after the enlargement on 1/7/2013
GHG	Greenhouse Gas
HNV	High Nature Value areas
IARC	International Agency for Research on Cancer
Kg	Kilogram
LCA	Life Cycle Analysis
LSU	Livestock Unit
MDE	Meat Dairy and Eggs
Mha	Million hectares
MS	Member State
Mt	Megatonne (1 million tonnes)
N	Nitrogen (reactive nitrogen)
NDR	National Dietary Recommendation
NH_3	Ammonia
NO_x	Nitrogen Oxides
N_2O	Nitrous Oxide
RDA	Recommended Dietary Allowance
SDG	Sustainable Development Goals
SOS	Safe Operating Space
Tg	Teragram (1 million kg)
WHO	World Health Organisation

PREFACE
by Janez Potočnik

It was during the RISE Foundation's research for the 2016 report on nutrient recovery and reuse in European Agriculture, that we first began to see how livestock – its production and consumption - is at the heart of so many of the challenges we struggle in agriculture today. The evidence concerning the sector's contribution to greenhouse gas emissions, and the impact of the leakage of nutrients from the sector to air and water, cannot be ignored. And as governments grapple with food security in an increasingly populated world that is already feeling the devastating effects of climate change, the inefficient use of resources by livestock is rightly being questioned.

But we also became aware of the disjointed aspect of the debate. Of a growing chasm between different stakeholder groups defending a cause or calling for change and a lack of crucial connectivity between addressing challenges around production *and* consumption.

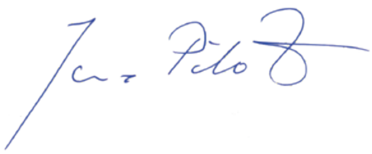
The RISE Foundation is a public utility foundation. We aim to provide unbiased and balanced perspectives concerning areas of European agriculture. We do this by tackling issues that often inspire great debate among those representing a particular sectoral, ideological or interest group, who will often have a silo approach to what are multi-faceted challenges requiring a combination of approaches.

We cannot shy away from the mounting research that is detailing the impacts of livestock production and consumption on our health, environment and climate. Whilst the massive advances in innovation in the livestock sector will certainly form part of the solution, it will not be enough. The shift needed for the sector to contribute to Europe meeting its commitments under the Sustainable Development Goals and the COP21 Paris agreement is just too great. And change is inevitable.

We are going through one of the most disruptive periods of recent decades across multiple sectors – mobility, housing, advertising, banking... and farming. Transition to a more sustainable production and consumption model will not be easy, but it can present enormous opportunities for those who are willing to engage in the process.

With this report we aim to call upon policy makers to use the range of policy tools at their disposal to support the sector through a necessary and inevitable transition. These will be uncomfortable messages to hear for the many who work hard to earn their living in volatile times by producing the livestock products that so many of us love to consume. But unless policy makers face up now to the need of the European livestock sector to adjust, and support the sector through that transition, the sector will pay the price of their inactivity. Protecting the status quo is providing a disservice to the sector.

The livestock industry should recognise the emerging evidence of the impact of their sector and actively engage in the necessary transition. And society should recognise livestock producers as partners for change: the majority of who have acted and invested in the evolution of the sector in good faith. They need and deserve public support for the transition to make it fair and viable. It is time to act so that we have the time to support a well ordered and structural shift to a form of European agriculture that is more sustainable. This is not only necessary, it is also unavoidable.



Dr Janez Potocnik
Chairman, RISE Foundation

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Executive summary

Scope and introduction

This report is about farmed livestock in the EU; cattle, sheep, pigs and poultry[1]. It deals with both consumption of livestock products – meat, dairy, eggs and other products – and the associated production of the animals and the feed they consume. These issues have global implications. The EU has high and matured levels of consumption of livestock products and a highly developed agricultural and food system. It is a significant player in global livestock genetics, animal health and technology and in production, consumption and trade in livestock products and animal feeds. Furthermore, some of the issues, particularly greenhouse gas emissions, atmospheric and water pollution and biodiversity loss from land use change, affect the global commons. Therefore, this report considers the EU contribution to livestock consumption and production within a global context.

Back story

Since the turn of this century, evidence has accumulated that livestock have become out of balance. Key publications have been FAO´s Livestock's Long Shadow (2006)[2], and the assessments of nitrogen and phosphorus flows by Sutton et al. (2011)[3] and van Dijk et al. (2015)[4]. Together with the influential report on planetary boundaries by Rockström et al (2009)[5], there is a strong case that livestock are already outside sustainable limits for Greenhouse Gas (GHG) emissions, nutrient flows and genetic biodiversity loss. Given expected population and income growth in transition and developing countries, and the dietary transition involving higher livestock product consumption which will accompany this, the judgement is that this certainly pushes livestock outside feasible and acceptable boundaries. How should the EU react?

The central idea of this report is that there *is* a safe operating space (SOS) for livestock. It lies between the lower boundaries defined by level of livestock production and consumption which offer sufficient health, cultural, environmental, social and psychic benefits of farmed animals, and the upper boundaries defined by the sustainable thresholds for the negative impacts on health and environment and acceptable animal welfare. The practical questions are how to identify this safe operating space, and how to move consumption and production into this space.

1 Fish are not embraced in this report; the substitutability between the fish and livestock products in consumption and production is acknowledged, but the expertise of the analysts was already stretched by considering the wide range of issues for terrestrial livestock.
2 Steinfeld, H., Gerber, P., Wassenaar, T.D., Castel, V., Rosales M., M., Haan, C. de, 2006. Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations, Rome.
3 Sutton, M.A., et al. (Eds.), 2011. The European Nitrogen Assessment. Cambridge University Press, Cambridge, pp.612.
4 van Dijk, K.C., Lesschen, J.P., Oenema, O., 2016. Phosphorus flows and balances of the European Union Member States. Science of The Total Environment 542, 1078–1093.
5 Rockström, J. et al., 2009. A safe operating space for humanity. Nature 461, 472–475.

Benefits of Livestock

Farmed animals have an essential place in Europe's culture. Europeans consume livestock products because they enjoy them. Most Europeans consume livestock products because they feel these products contribute to their wellbeing. Meat, dairy products and eggs provide high-quality protein, minerals, vitamins and other essential nutrients. We have an emotional connection to animals in the countryside. Second, ruminant livestock, principally cattle, sheep and goats, consume cellulosic materials such as grasses which humans are unable to digest. This enables large land areas not suitable for crop cultivation to produce food. In the process, many pastoral areas provide a wide range of treasured cultural landscape and ecosystem services. Third, it is claimed that livestock are admirable exponents of the circular economy; they make use of a wide variety of crop by-products and residues and food waste, and they cycle nutrients and organic matter back to crop production. These are true, but there are alternative ways of utilising residues and wastes. Neither can it be overlooked that animals are inefficient and leaky nutrient managers. Whatever livestock society chooses to keep, it is vital that there is careful management of manures and maximum recovery of nutrients, but it cannot be claimed that livestock add nutrients to the system.

Negative impacts of livestock

The first are the GHG emissions, mostly methane and nitrous oxide from animals, their manure, and from the production of their feeds. Second, is the leakage of the nutrients nitrogen and phosphorus and their compounds which cause serious water pollution and eutrophication, and air pollution. Third, there is direct and indirect degradation of biodiversity through land use change and degradation of soils by production of livestock and feed crops. Fourth, negative human health effects from livestock can arise as respiratory disease from air pollutants, especially ammonia, from anti-microbial resistance (AMR) and zoonoses, and risks of certain cancers increase with the consumption of processed and red meat products. Also, a general, over-consumption of livestock products (and sugars) has led to a serious rise in obesity and an associated constellation of chronic and damaging diseases including diabetes and coronary heart disease. Given the innate inefficiency of biological processes involved and the leakiness of livestock production, the over-consumption of animal protein, which is simply burned for energy, represents a grossly wasteful and damaging use of scarce resources.

The evidence on these benefits and negative impacts of livestock is reviewed in Chapter 2 of the report together with summary data on the scale of EU livestock consumption, production and trade.

Defining and quantifying a Safe Operating Space for livestock

This is a developing area of science, which has not been attempted at a sub-global level for a specific economic sector, i.e. EU livestock. Some boundaries e.g. climate protection, are truly global. Others e.g. biodiversity are partly global and party local, and some e.g. freshwater pollution only make sense at river basin or landscape level. Furthermore, there are important interactions between the underlying factors which means that the boundaries are not independent of one another. These considerations complicate the analysis.

Four boundaries of the livestock SOS were examined using data for the EU28 and the individual Member States (MS). They were: lower boundaries for human nutrition and for utilisation of pasture, an upper boundary for GHG emissions, and what was expected to be an upper environmental boundary for nitrogen flows. The analyses are simple and broad brush and offered as preliminary approximations of the order of magnitudes involved.

A lower boundary for human nutrition

To capture the idea that livestock products provide high quality nutrition for human development and life this lower boundary was expressed as the proportion of current consumption which would satisfy the National Dietary Recommendations (NDR) published by the health authorities of the MS. The results for meat showed, on average the populations of all MS are consuming more than the recommended amounts. 19 of the MS, and the EU28 on average, are consuming more than twice the recommended level. The excess consumption of dairy products is less pronounced. The average EU28 consumption level is just 5% over the recommended level, with 11 MS consuming less than the recommended levels. 17 MS are consuming above the NDR for dairy products, six of which are more than 20% above. Egg consumption follows a similar pattern as dairy products, with 17 MS consuming above the NDR, several with excess of more than 30%. With such wide variation between MS, average boundaries for the EU28 are not helpful. Broadly, the human nutritional lower bound for meat is in the region of 40% of current consumption for the countries over-consuming most and 60% of current consumption for most others. The dietary lower bound of livestock for egg and milk consumption in the two-thirds of MS which are over-consuming is about 80% of current consumption for eggs and 80% to 90% for milk.

A lower boundary for pasture utilisation

This was defined as the minimum number of ruminant livestock units needed to ensure the conservation of permanent pastures in the EU and the associated habitats, biodiversity, landscape and communities to avoid their conversion into arable land, scrub, forest or even urbanisation. It was calculated by dividing the areas of permanent and rough grazing by stocking rates chosen to reflect sustainable management of these pastures. Stocking densities, 0.5 and 1.0 LSU/ha, were used to bracket this sustainable rate.

The results show all MS except five (Romania, Lithuania, Bulgaria, Latvia and Estonia) would require fewer ruminant livestock than now to utilise all permanent pasture. Under the low stocking rate assumption, the proportion of current animals justified to maintain pastures is small, less than 30% for 11 MS including the three MS with the largest grazing livestock populations (France, Germany and Italy). Another 14 MS could justify from 30% - 60% of current livestock units. Only Bulgaria and Romania could justify two-thirds or more of their current grazing animals if the lowest stocking density correctly defines the sustainable intensity. These minimum numbers are correspondingly higher under the higher stocking rate. These are coarse estimates and do not take into account grass quality or availability, nor the economic viability of grazing enterprises at low stocking rates. Additional livestock could be supported if rotational grass and crop by-products and residues were included in the analysis.

Upper boundaries for climate protection

The position of the climate boundary in relation to current livestock activity is initially indicated by calculating the percentage reductions from 2013 in direct livestock emissions necessary to achieve the EU's GHG target cuts set following the Paris Climate Agreement of 40%, 60% and 80% by 2030, 2040 and 2050, respectively. Agriculture is not formally included in these targets and the commitments. The calculations show the adjustments needed in livestock emissions if this sector is not gradually to become a growing share of remaining emissions as energy supplies are decarbonised.

The results show the average EU28 reductions required are 21%, 47% and 74% respectively for the three dates. Because emissions in the ten central and eastern MS have fallen so much since 1990 these countries have space to expand their livestock emissions and remain within national targets at 2030. The range in reductions required by 2030 for the other MS is from 18% for Germany to 47% for Cyprus. With respect to the 2040 target, only Bulgaria, Slovakia, Lithuania and Latvia have any further scope to expand livestock emissions, the reductions for the other 24 MS range from 12% for the Czech Republic to 65% for Cyprus. To reach the 2050 target of 80% reduction, all MS must reduce emissions by between 37% (Bulgaria) and 82% (Cyprus). Taking the Paris emission reduction targets as indicators of the upper boundary of the SOS indicates that current production levels are way outside this safe space.

Boundaries for nutrient flows

The planetary boundaries related to biogeochemical flows, specifically nitrogen (N) and phosphorus (P) refer to the excess amounts of reactive N and P that are released into the environment causing eutrophication. For N, the four main sources are: industrial fixation of N_2 into ammonia, biological fixation via agricultural leguminous crops, the combustion of fossil fuels and the burning of biomass. The global N boundary was defined and initially set by Rockström et al. (2009)[6] at 35 Mt N yr^{-1}. Following criticisms by de Vries et al. (2013)[7] that this boundary does not take human needs into account—it was revised to 62 Mt N yr^{-1} (Steffen et al., 2015)[8]. This calculation was based on the levels of protein necessary to provide adequate nutrition for the human population. The global figure was then downscaled to the country level by expressing the limit per head of population using the factor suggested by Kahiluto et al. (2015)[9] of 8.6 kg cap^{-1} yr^{-1}. This was multiplied by the population of each MS bringing the boundary to a more spatially relevant national level.

The national boundaries for nitrogen fixation were then compared to EU data on annual nitrogen fixation which were calculated as the sum of manufactured fertiliser consumption and biological fixation by leguminous agricultural crops. Of course, part of this N fixation is not related to livestock production, but to crop production.

Comparing the calculated boundaries for N fixation with the annual fixation taking place the results show large adjustments are necessary to respect the national boundaries. For the EU28 a 65% reduction of the fixation would be required to get the system inside the boundary. The range in reductions for individual member states is from 35% for the Netherlands to 90% for Ireland. The reduction required is greater than 50% for 20 MS and over 75% in eight MS.

These highly aggregated results must be interpreted with care. They do signal a serious imbalance. However, they tell us nothing about the regional concentration of nitrogen which varies widely within countries. This spatial variation does however offer an additional strategy to move towards the SOS by de-concentrating and relocating some livestock activity and re-integrating it with crop production. Conceptually this boundary is not as soundly

6 Rockström, J., et al., 2009. Planetary Boundaries: Exploring the Safe Operating Space for Humanity. Ecology and Society 14:32.

7 de Vries, W., Kros, J., Kroeze, C., Seitzinger, S.P., 2013. Assessing planetary and regional nitrogen boundaries related to food security and adverse environmental impacts. Current Opinion in Environmental Sustainability 5, 392–402.

8 Steffen, W., et al., 2015. Planetary boundaries: Guiding human development on a changing planet. Science 347, 1259855.

9 Kahiluoto, H., Kuisma, M., Kuokkanen, A., Mikkilä, M., Linnanen, L., 2015. Local and social facets of planetary boundaries: right to nutrients. Environmental Research Letters 10, 104013.

based as that for GHG. The practical adaptations to Rockström's approach have, in effect, turned it from an upper bound of environmental capacity to minimise eutrophication to a human dietary lower bound. This demands further work and to complete the picture on the nutrient boundary of the livestock SOS, phosphorus must be included.

Boundaries for other benefits and negative impacts

There is no scientific way to determine a lower bound of livestock production and consumption based on cultural preferences. Similarly, whilst the provision of livelihoods from the livestock sector is of immense economic, social and political importance, there is no objective way to define minimal levels of employment and economic activity. These are outcomes of markets, technology and policy. No progress has been made on quantifying the boundaries for the other variables on which livestock production has significant negative impacts, biodiversity and land degradation, anti-microbial resistance and zoonoses and animal welfare. For all these variables, there is no doubt that they raise critical concerns about livestock product consumption and production. Indicators of the scale of the, mostly negative, impacts that livestock production has on these variables are available. However, there is no obvious objectively measurable criterion which defines an upper boundary of acceptable impacts.

Conclusions on defining SOS boundaries

This field of inquiry is promising but is in its infancy. The nutrient boundary demands more research and further work is needed on the other impacts of livestock. Preliminary indications to this point are:

1. EU livestock production and consumption are not in their safe operating space.
2. Current EU livestock production is associated with greenhouse gas emissions and nutrient flows which are currently far higher than the upper boundaries of the SOS and is therefore unsustainable. Reductions in these leakages of the order of 60% or more are indicated.
3. Current livestock consumption and production are considerably greater than the lower boundaries of the SOS based on national dietary recommendations and on pasture utilisation. Also, the boundaries established for these two variables imply production levels greater than those required to respect the upper boundary for GHG emissions.
4. These findings imply uncomfortable choices for society. However, it is clear that respecting the upper environmental limits should take precedence over the cultural lower boundaries.

Options to bring livestock into a Safe Operating Space

Whatever level of EU livestock production, now and in the future, it is essential that continued progress is made on four fronts: improving resource efficiency, reducing leakages into the environment, increasing the health status and welfare of farmed animals, and minimising the use of antibiotics. A key question is whether sufficient improvement in these four areas can be made to get the sector into a SOS. If this is not possible then active steps to modify consumption behaviour are unavoidable.

Adjusting livestock production

None of the four actions listed above are new ambitions. They are all receiving considerable attention some have been pursued for decades. These have focussed on optimising breeding, feeding, housing and maintaining healthy animals to increase production per unit of livestock, and per unit of inputs into the system. Explicitly embracing environmental standards and reducing reliance on anti-microbials is newer but it is now an overt and active part of the resource efficiency drive, with particular emphasis on reducing GHG emissions.

Europe has produced a great many research and advisory reports offering actions to reduce GHG emissions, nutrient leakage, loss of biodiversity and land degradation. Reducing GHG emissions and nutrient leakage can be approached by changes in feed and changes in manure management. Four strategies on feed are to improve feed conversion ratios, introduce novel feeds, reduce emissions from the feeds themselves, and by manipulating microbial action in the rumen perhaps with feed additives to reduce methane production. Manure management options include covering storage, aerating or composting manure, and processing it in a variety of ways, including anaerobic digestion, to recover nutrients and energy. Nutrient leakage can also be tackled by de-concentrating livestock production and re-integrating it with cropping systems, including more rotations and making greater use of legumes.

There is considerable scope for further innovation in livestock production, four areas are discussed. Digital technologies and precision livestock farming could substantially improve the monitoring of animals their health, nutritional, reproductive and welfare status enabling more timely and precise management to improve health, welfare and thus productivity. Second, new breeding, genetic and genomic techniques offer much potential: to improve disease resistance and feed efficiency of farm animals themselves and also in the speed and effectiveness of development of vaccines. While promising, access to some of these technological advances may not be accessible to all farmers, especially those in marginal areas with low incomes. A third area of innovation is in the development of new sources of animal feed which may reduce environmental impacts and demands on land and water. Two such possibilities are insects and alga culture. A fourth area for innovation is in the processing of animal and other wastes to recover and reuse nutrients.

The fact that these approaches to improve efficiency are familiar is reassuring, but it also implies that without a step change in technology, or in motivation and stimulus, it is unlikely that the future rates of efficiency gain and leakage reduction will be higher than those achieved in the past.

This specifically applies to GHG emission reduction. The core of the methodology for estimating GHG emissions from livestock in national GHG inventories is to take the product of an emission factor for each animal type and the number of such animals. Measured emissions can therefore be reduced by a fall in the emission factors and/or by reducing the numbers of animals. Reducing emissions per animal requires efficiency improvement by changes in breeding, feeding and managing animals and their manure. This is proving difficult and slow. Progress might improve as the challenge is better understood and as more public and private research resources and policies are deployed specifically to reduce methane production in cattle and to better manage manure. However, to achieve the targets for GHG reductions this would imply sustained annual reduction in emission rates per animal in the order of 3.5% per annum. Such rates of productivity improvement have not been seen in EU agriculture for a long time, and never sustained over a period of decades. **The conclusion is** that whilst the flagged areas for innovation are highly promising, they do not offer the step change required. If GHG emissions from livestock are to be reduced in line with the internationally agreed targets then this will necessitate a mixture of efficiency gain ***and*** for most EU MS, reduction in livestock numbers too. It is most likely that the same is true for nutrient leakage. Continuing to improve livestock production efficiency is essential, but options will also have to be pursued to change consumption of livestock products.

Adjusting livestock consumption

Three categories of consumption change are considered, starting with the least radical.

Change species and systems mix. There are large differences in efficiency and environmental impact per kg of product between the species, and between production systems within species, e.g. grass fed versus concentrates-fed beef and dairy. Changing species mix, and production systems mix of livestock consumed could therefore bring about significant reduction in some negative impacts. However, the impacts on *all* the variables of interest - climate, water, air, biodiversity, landscape, health, AMR and welfare – must be considered and these will sometimes go in opposite directions. The result, especially given the multitude of different production systems, is that there are few switches which offer unambiguous gains in all variables. Furthermore, trade-offs between reduced emissions and leakage versus welfare impacts are not easily assessed objectively. Environmental impacts could be far better controlled if animals were completely contained, but this involves a trade-off with the welfare of the animals. Society must decide its priorities.

Choose alternative 'animal' protein. Two potential sources of alternative protein which humans could substitute for farmed meat, eggs and dairy products are ***insects*** and ***cultured meat***. Both substitutes are a response to societal concerns about the impacts of livestock on the environment, human health and animal welfare. Insects as food are regulated under the EU Regulation on Novel Foods[10]. Their presence in EU markets is limited to date. The potential environmental benefits of insects in comparison to livestock are reducing GHG emissions, and water use, freeing up land, and reducing bones and offal, and food waste. Consumer acceptability of insect-based foods or ingredients is a major issue. Regulatory hurdles include the safe containment of insects, the availability of consistent supplies of feedstock for the insects, risks arising from disease spread or allergic reactions. It is likely that the marketing effort required for insects will be much higher for human consumption than for animal feed so the initial major initial developments with insects to prove the concept are likely to be for the latter.

Cultured meat is animal tissue produced in laboratories from animal cells. There are many efforts in the EU and elsewhere to develop this commercially. The promised environmental benefits are similar to those claimed for insects and could be substantial. Other advantages are the reduction in antibiotic use and an ability to control the amount of fat, nutritional value and taste. However, the production of cultured meat is also an energy intense process and considerably more development and assessment is necessary before these claims can be confirmed at scale and the impacts on human health and the environment measured. There are also controversial issues concerning the use of serum from animal blood in some culture techniques.

In short, whilst insects and cultured meat will undoubtedly be further developed, these two substitutes are a long way from making a significant contribution.

Reducing total livestock protein, substituting plant protein. The above two options of finding the

10 Regulation (EU) 2015/2283 of the European Parliament and of the Council of 25 November 2015 on novel foods

least damaging mix of livestock products or finding new substitutes are helpful but they have limitations. The unavoidable conclusion is that total livestock product consumption must contract.

Quantitative analyses of the environmental and health benefits of reducing livestock product consumption are gaining attention. They implicitly or explicitly assume that production is reduced equally across the species, and that all products are reduced proportionally. Several studies conclude a 50% reduction in current consumption of these products in the EU would make a significant contribution to climate change mitigation and align current intake of animal protein and fats with WHO recommended dietary guidelines. Such a reduction could result in 40% less reactive nitrogen emissions from agriculture, reducing eutrophication and acidification in aquatic environments. These studies estimate 23% less cropland area would be needed if livestock were reduced by half. Following national dietary recommendations would result in significant reductions in GHG emissions, eutrophication and land use globally. The effect of a large change in livestock product consumption for animal health and welfare is not analysed. Neither have the economic and social impacts been analysed. These dimensions should not be assumed but investigated.

What replaces the livestock product? If consumption of livestock products is reduced people may not eat less, they will eat differently, with different responses for each demographic group. The products which replace livestock will determine the effective impact of reducing livestock consumption on human health and the environment. Environmental benefits may also not automatically appear from reduced livestock product consumption. Some vegan and vegetarian diets with high consumption of proteins and fats could have a larger carbon footprint than omnivore diets, although in general the contribution to GHG emissions is larger for the latter. Examples of possible replacements are: the replacement of milk by vegetable-based drinks from cereals, legumes, nuts or seeds, and vegetable material sold in the shape of sausages and hamburgers, some of which are made to taste like meat but have a reduced environmental impact. Other alternatives to animal-based protein are pulses, nuts, algae and soya. A widely consumed and well-studied meat substitute launched in the mid-1980s is a mycoprotein-based product Quorn, derived in a continuous fermentation process using the fungus Fusarium venenatum. Its story provides an interesting insight into the many years it takes, and the technical, regulatory and marketing hurdles which must be overcome, to develop novel foods at scale.

Concluding remarks on options to get to the SOS. A wide range of practicable actions is already known which could help adjust the sector. The actions on livestock production and on consumption are not mutually exclusive, they all have a contribution to help the sector back to a SOS.

The scale of change indicated may seem high and unattainable. But the livestock sector has experienced significant change in many countries and sub-sectors. For example, the 20% reduction in GHG emissions from agriculture experienced between 1990 and 2015 was driven largely by a reduction in livestock numbers (cattle and sheep) and a reduction in the use of nitrogenous fertilizers according to Eurostat. There have been periods of quite large cuts in pig numbers in the Netherlands and UK, and in sheep numbers in the UK. Red meat consumption is already on a downward trend. Change is occurring and can be managed.

Conclusions, policies and recommendations to move livestock into a Safe Operating Space

Although the 'livestock challenge genie' is well out of the bottle, it has not yet been seized by European governments as an identified strategic policy issue. The extent and dangers of the principal negative impacts of livestock are well analysed in scientific literature. Environmental NGOs have long campaigned on the issue. However, livestock have not yet enjoyed a 'Blue Planet' moment[11] as occurred for plastics when public and governments seize this as a strategic issue demanding real action. To date neither EU policy, nor that in any Member States, has yet chosen to focus public attention on 'the livestock problem' as such. It is now time to do this.

Part of the problem is that policy is compartmentalised, yet the livestock challenge spans health, food and agriculture, the environment including climate change and economy. Also, the EU does not have prime competence in health matters. Nonetheless a more strategic EU food system approach is required. Because the issues involve traded goods this must be grasped at EU level, although as consumption patterns and production systems vary around the Member States, the concrete actions will inevitably be devolved to that level.

The adjustments suggested are very large so discussion of these issues is deeply uncomfortable to the very substantial economic interests of producers in the whole livestock chain, who are very aware of the challenges. Their response, not unnaturally, is to suggest that the positive impacts of livestock are insufficiently noted and the neg-

11 This refers to the 2017 BBC Programme series with this title presented by Sir David Attenborough which graphically filmed the far-reaching impacts of plastics on ocean life, and which has spurred a step change in public awareness and, it is hoped, government action.

ative impacts are exaggerated. There is a reluctance to accept that livestock is outside the SOS. Whilst there is acceptance that action to reduce negative impacts is needed, the hope is that technical progress on the production side will be sufficient.

These observations prompt the primary conclusions and recommendations of this report:

R1 The EU should set up a formal inquiry to investigate the following questions.
- ***Where is the safe operating space for EU livestock?***
- ***What adjustments in production and consumption are necessary to get into it?***
- ***What policy measures would be required to propel these adjustments?***
- ***What would be the impacts on health, environment and the economy of these changes?***

The challenge is immense and complex because the scale of change in livestock production and consumption necessary to get the EU sector into its safe operating space is large, and it will require action from all participants in the livestock food chain and a large proportion of consumers. The task is most definitely not the elimination of livestock, but a substantial contraction of its harmful environmental and health effects by whatever actions can be agreed to achieve this.

R2 It is suggested that the change must be a citizen-led, consumer-led, enterprise. Although it requires action by both consumers and producers the transition required will only occur if driven by consumers. This will not happen spontaneously but only if Government takes strong action to spur the necessary changes.

Change will not be brought about by a frontal assault on the livestock production sector. Rather the predominant driver for change should be citizens' pressure for the amelioration of environmental and health damage from the production of livestock products they buy and consume.

Yet constructive change will go better and faster once producer interests are persuaded that the changes are unavoidable as the present trajectory of livestock is simply unsustainable. The changes are challenging: new livestock production modes will require new science and technology, which, in turn, demands research and investment. This will be hard to secure for a sector which, overall, may have to contract. This is why public assistance will be necessary to manage the transition. It should be made clear that resources will be available to help businesses with stranded assets to adjust.

Encouraging sustainable consumption of livestock products in the EU

Given the wide range of influences on what people eat, an equally wide range of tools will be necessary to help them change what they eat. The approach required may be different depending on the prime reasons for changing consumption, whether it is to do with environment, climate and animal welfare concerns, or consumers' own health and that of their family.

The actors to bring about change in consumer behaviour must include businesses in the food chain, civil society, governments and collaborations of all these. Wellesley et al. (2015)[12] classified actions into three groups: first, to inform and empower for example through labelling and information campaigns, second to guide and influence, e.g. by nudging, and third to incentivize, discourage or even restrict with taxes, subsidies, bans or standards. Each actor has potential actions under each of these headings. Such interventions will have a range of effectiveness with different demographic groups.

The sheer immensity and complexity of the livestock challenge, and the needed response, is such that public authorities must be prepared to take bold initial steps to overcome the inevitable inertia. Without such a jolt or shock there will be insufficient action.

R3 A mandated output of the proposed inquiry should therefore be a suggested set of policy proposals which include measures to discourage consumption of livestock products harmful to health and environment, and to encourage consumption and production beneficial to health and environment.

To be meaningful these must include interventions which include, but go beyond, informing, empowering, guiding and influencing, i.e. taxes and subsidies. Considerable further thought and analysis is required to determine at what level and in what way to impose such taxation. Because the subject of the tax is basic foodstuff such proposals must include consideration of necessary accompanying welfare provisions. The imposition of over-consumption taxes and implementation of changes in social welfare are of course matters for Member States but to avoid distortions in the EU single market they must be coordinated at EU level.

12 Wellesley, L., Happer, C., Froggatt, A., 2015. Changing Climate, Changing Diets Pathways to Lower Meat Consumption. Chatham House Report 64, London, UK.

Encouraging sustainable production of livestock products in the EU

Proposals for EU-wide taxes on livestock product consumption harmful to health and environment will take considerable time to debate and implement. Meanwhile further policy action can and should be taken to help livestock production move towards the SOS. This should work on three fronts.

> ***R4 Policies must encourage: structural change in farming, to bring about a better balance, structure, location and de-concentration of livestock and better integration of crop and animal production, as well as resource efficiency improvements and reduction of leakage and waste.***

There is extensive literature on policies which could assist resource efficiency and leakage reduction, but there is a research deficiency on structural change. Policies which can help achieve these objectives include but must go much wider than agricultural policy. They must also cover policy for: the environment, animal health and welfare, research, development and technology, and food chain engagement. Most of this is well-trodden ground, the missing ingredients are the conviction that it is necessary to act by the relevant authorities, and willingness to change on the part of the food chain. Two policy sectors merit particular attention.

For environmental policy, the key recommendations are:

> ***R5 Implement existing environmental regulations and directives.***

More specifically,

> ***R6 Help farmers better manage the environment on their farms by assisting establishment of better farm-level environmental performance indicators, benchmarks and plans for GHG emissions, nutrients and biodiversity.***

EU agricultural policy enshrined in the CAP has continuously, but rather slowly, evolved to adapt to emerging challenges. It is suggested that with one exception the CAP already contains most of the main kinds of measures which are required to steer agriculture, especially livestock, into its SOS. The major exceptions are the diagnosis of the scale of the transformation required and consequently the recognition that this will require significant structural change in farming and active measures to foster transition to sustainable businesses. The proposed high-level inquiry will help make this case.

The CAP has tended to inhibit rather than encourage and enable structural change. Sustainable farm businesses should not be undermining the soils, biodiversity, clean water and climate on which they depend, they should be commercially viable without annual handouts, and embedded in lively, diversified rural communities. The CAP is the correct and obvious policy framework to provide the assistance that is needed to bring this about. Only when it is openly recognised and explicitly acknowledged by the agricultural policy community in the EU that the balance of the agricultural sector must radically change to reduce the scale of the negative impacts of its livestock component will it be possible then to plan for the adjustment assistance required. The most important change required in the CAP is to its direct payments, including the coupled, payments. As proposed in the previous RISE Foundation report[13] the principal recommendation for Europe's agricultural policy is to:

> ***R7 Better target the Pillar 1 resources currently provided as direct payments, by deploying them to stimulate and enable structural changes required to help the livestock sector make the transition to a SOS.***

The aim should be to emphasise the positive reasons for the change, to improve health and the environment simultaneously whilst developing new technologies and new markets. These expanded markets will be for plant based protein, fruit and vegetables, nuts and pulses, for cultured protein and for novel sources of protein such as insects and algae. New technologies will also have an important role in changing the character of continuing conventional livestock production. A realistic period for the change is measured in two or three decades to give time for changes in technology, institutions and social attitudes and consumer behaviour.

Research policy. The proposed inquiry will discover that there are gaps in our understanding of many issues and data gaps, one of its tasks must therefore be to identify the research agenda and data collection necessary to guide action. Two issues are singled out for specific attention.

> ***R8 An important task for the proposed inquiry is to develop a better conceptualisation and measurement of the ceilings or upper boundaries of the safe operating space especially with respect to nutrient flows and biodiversity.***

13 Buckwell, A., et al., 2017. CAP: Thinking Out of the Box. Further modernisation of the CAP - why, what and how? RISE Foundation, Brussels.

It is important that as farmers adopt more efficient practices which improve their resource efficiency and reduce the emissions per unit of output that the official inventories measuring emission properly account for the changes taking place on the ground. Therefore,

R9 It is essential that GHG emission factors for livestock are regularly updated to reflect the expected, and necessary systematic improvements in resource efficiency.

International impacts of the EU moving to its SOS

The EU is a significant participant in international trade in livestock products, importing animal feed and exporting: animal technologies, genetics and health products, high value processed meat and dairy products, and some lower value meat and products. Despite the protection the livestock sector enjoys behind the EU common external tariff and the generous support of the CAP, a fear of producer interests when higher environmental or animal welfare standards are discussed is that this will impose additional costs and render domestic production less competitive with suppliers abroad. They claim raising standards will therefore hurt domestic producers and may displace local production in favour of imported goods produced to lower standards. This is often described as displacing and increasing pollution. Given the complexity of tackling the livestock challenge and the difficulties of coordinating the quite different measures applied to consumers and producers, it is quite likely that there will indeed be different rates of progress on reducing consumption and reducing production especially for individual products amongst the wide array of livestock goods. For some products, domestic consumption may contract more quickly than production, and the EU or a Member State may find its livestock product exports growing. This will invite criticism that the EU is suffering the pollution of other people's unsustainable consumption habits.

Three responses are offered to these concerns.

The first, and the most important is that if it is the case that current livestock consumption/production levels are demonstrably unsustainable in the sense that they are approaching, at, or beyond boundaries which mean indefinite continuation of the activity is not possible, then corrective action is unavoidable. This *is* thought to be the current situation for livestock production.

Second, is the need for debate on these issues to be based on sound data assembled by trusted institutions under internationally agreed methodology. To make judgements on whether certain trade flows increase or diminish environmental damage globally requires scientific studies on impacts on each environmental medium of marginal future changes in production, and for this to be available on a comparable basis for the main trading countries across the world. This requires coordinated international research which the EU can lead.

Third, for two of the most important environmental challenges, climate and biodiversity protection, there are already in place international agreements (Paris 2015, and Nagoya 2010) in which signatories, which include most of the largest trading countries, have agreed to actions, respectively, to limit GHG emissions substantially, and to halt degradation and encourage restoration of biodiversity. Therefore, if the EU takes actions which limit its own livestock output more than it reduces consumption, and if this results in expanded production and increased exports to the EU from some other part of the world then the exporting countries will be obliged to accommodate this within their own commitments under international agreements. Such countries will most probably also discover that they too are obliged to address GHG from livestock if they wish to meet their Paris agreement targets. Dissatisfaction and distrust of this response is distrust of international agreements.

Final words. Technical and economic change in the last seven decades have dramatically reduced the real cost of food and enabled an expansion of consumption of all foods to the extent that populations are eating themselves into ill health by consuming way beyond dietary advice. The livestock component of this over-consumption demands priority attention because of the intrinsic inefficient and leaky nature of animal production which results in serious environmental damage. The concerns expressed should not be viewed as an attack on livestock, but an attack on the negative health and environmental impacts of over-consumption of their products.

A more positive and more confident observation is that as a highly developed bloc, with a strictly regulated and well-supported farm and food sector, the EU and its standards are internationally trusted. Chinese dairy and meat imports from the EU are partly motivated by the greater trust endowed in high quality EU products. EU regulations are emulated and matched by many other countries. ***Europe should be confident that if it takes the lead in defining and moving to a safe operating space for livestock this can help set the standards and procedures which others will follow.*** Such first mover advantage will itself provide opportunities as Europe develops the information, motivation, messages, technologies, and policies for more sustainable, balanced livestock consumption and production.

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1. Introduction: livestock consumption and production are out of balance

The study reported here is about farmed livestock – cattle, sheep, pigs and poultry[1]. Its primary focus is livestock in the EU, both consumption of livestock products- meat, dairy, eggs and other products – and the associated production of the animals in the EU and the feed they consume. The issues raised by livestock have global implications. The EU, as the world's largest economic area, has high and matured levels of consumption of livestock products and a highly developed agricultural and food system. It is a significant player in global livestock technology and production, consumption and trade in livestock products and in animal feeds. Furthermore, some of the issues – particularly atmospheric and water pollution and biodiversity loss – affect the global commons. Therefore, this report considers the EU contribution to livestock consumption and production within a global context[2].

Most Europeans consume livestock products first and foremost because these products contribute to their well-being. Meat, dairy products and eggs provide high-quality protein, minerals, vitamins and other essential nutrients. We consume livestock products because we enjoy them. There is the deep-seated cultural attachment to consumption of meat, eggs and dairy products. Of course, this is expressed in different ways around the world and amongst the regions and peoples of Europe, and as will be discussed, these cultural tastes and preferences evolve as economies develop. But it is a safe generalisation to say that meat, eggs and dairy products are central to diets for most citizens in most countries, certainly in Europe and other parts of the developed world. The so-called 'main' course in the largest meal each day in many cultures is commonly defined by the meat it contains[3], and any preceding and/or following courses invariably contain some dairy products. It is also empirically observed that as income levels rise, in most countries, the consumption of livestock products rises[4].

A third major benefit of livestock production is that ruminants (principally cattle, sheep and goats) consume biomass – particularly cellulosic materials such as grasses - which humans are unable to digest. This enables large land areas not suitable for crop cultivation to produce food. Pastures and fodder from such land provides almost half of the feed consumed by the livestock sector.

1 Note this report does not deal with fish – marine or freshwater. The strong substitutability between the two in consumption and production is acknowledged, but the expertise of the analysts was already stretched by considering the issues surrounding terrestrial livestock.

2 Note also that although EU consumption and production are considered in the global context this only embraces the competing resource demands and environmental degradation issues, including of course climate change. In many developing countries farmed livestock have other important economic and social functions, as providers of transport and draft power and as stores of wealth. These are also issues beyond the reach of this report.

3 Vegetarian, and to a lesser extent vegan, dishes are of course now common on menus in many, but by no means all, countries of the EU. But the proportion of vegetarians and vegans in the population does not exceed 10% in any EU Member State.

4 In economic jargon the income elasticity of demand of livestock products are positive.

As well as their contribution of critical nutrients, the deep cultural attachment to livestock products, and the ability of grazing animals to utilise grass, a fourth benefit claimed for livestock farming is that farm animals cycle nutrients for crop production. For the system in total, of course, livestock do not supply nitrogen[5], indeed they quite wastefully use it. However, the use of manure offers a way of redistributing some nitrogen as well as returning organic matter to the soil. Nutrients in forage, grains, oilseeds and root crops are provided to animals. Subsequently, part of these nutrients is recovered in animal manure and cycled back to crops. This rural circular economy has been a component of many agricultural systems for centuries. Mixed farming systems consequently tend to have some element of rotation of land between pasture, grains, roots and protein crops and this provides benefits for biological disease prevention and control in crop and animal production, for biodiversity and provision of other ecosystem services. The proponents of all the major self-styled 'sustainable' farming systems – organic, bio, agro-ecological or permaculture – stress that central to such systems is a balance of animal and crop farming that enhance the natural functioning and resilience of agricultural systems[6].

Livestock, both ruminants and monogastrics (pigs and poultry) importantly also utilise a wide range and large volume of crop residues and by-products of milling and processing of cereals, oilseeds and dairy, as well as sugar beet tops, brewer's grains, and by-products from the baking and confectionary industries. Livestock are also fed food products that are fine for human consumption but do not meet market requirements (i.e. misshapen, broken or expired foods). These residues and by-products would otherwise be considered wastes from the human food processing and food service systems. This valorising of what would otherwise be large volumes of troublesome wastes contributing to the nutrition of farmed animals provides an important element of the economic viability in the crop production system. Crop-animal nutrient recovery and recycling and the utilisation by farm livestock of crop and food industry residues and by-products are long-established practices which are nowadays referred to as the circular economy. This is far from a marginal consideration. Together, grassland, roughages and by-products provide more than 50%[7] of farmed animal feed which cannot be utilised for human nutrition.

A large part of the area in the EU occupied by grazing animals is not capable of cultivation for crop production. In such land the only practicable way to provide food is through pastoral farming systems or agroforestry with grazing livestock. The livestock involved are generally, but not always, ruminants which can digest the cellulosic component of grass and other forage[8]. These grazing-based agricultural systems have been practiced in many areas for centuries, they have created valued natural and semi-natural ecosystems which characterise large tracts of marginal rural land in Europe covering approximately 35%[9] of the utilised agricultural area. The prized examples are often designated as high nature value (HNV) farming systems[10], and many indeed are designated as valued and protected areas under the EU's Natura 2000 system. Their societal contribution is the food products they provide and the environmental services of biodiversity, water quantity and quality management, and carbon sequestration in soil. Such regions are also associated with treasured cultural landscapes, rural heritage, customs, dress and cuisine. The combination of these food production and other activities is an important part of the employment, economy and society of such areas.

In short, for many centuries farm animals in Europe have been integral to human wellbeing and to economic, environmental and social sustainability in rural areas. They provide appreciated meat, dairy products, eggs, and of course skins, fibres and many other products. They help cycle nutrients by providing manures and by utilising crop residues and food processing by-products, and they make use of marginal land turning inedible grass and rough grazing into nutritious food for humans. In all these ways they contribute to human nutrition, rural livelihoods, cultural landscape and identities.

What could possibly go wrong with this system? It appears that six decades of steady growth in consumption and production have resulted in some strong imbalances. Especially since the late 1940s living standards and food consumption patterns of European citizens have been transformed. What people eat and how they consume food have changed out of recognition. Part of this

5 The only ways of fixing nitrogen are biological fixation by legumes, by natural processes (lightening) and in the manufacture of artificial fertilisers through the Haber Bosch process. Enduring crop systems are possible without livestock manure through natural recycling and composting part of the annual biomass increment.

6 Animal manure is a key element of soil fertilisation in all these systems. The FAO identifies 'designing food systems with an optimal crop/animal assemblage' as one of the key elements of agroecology.

7 EU livestock consume 470 Mt of dry matter annually, of which around half corresponds to roughages, one third of compound feed and the rest are cereals or purchased feedstuffs. By-products and co-products from the food and bioethanol industry represent 11% of the compound feed. (EC Agricultural Outlook 2017-2030).

8 Pigs and poultry can also have a foraging role in some production systems, such as the dehesas and montados in Spain and Portugal.

9 12% is unimproved grassland while 23% is managed grassland.

10 High Nature Value (HNV) describes the farming systems of greatest biodiversity value in the EU which cover around 30% of the agricultural land. In the northern MS it's around 10% while in the south it's up to 50% (Hart et al. 2012).

change in consumption has arisen from the dramatic changes in the technology and structures of livestock farming and processing. Much livestock production now takes place at a scale unimaginable 60 years ago, and has significantly reduced the real cost of livestock products. This is especially the case for poultry enabling what was once a meat for special occasions to become very widely available. Accompanying the changes in scale has been significant specialisation with regional and local concentration in production greatly increasing the density of livestock in some producing areas.

This has led to a situation which is increasingly suggested to be unsustainable. This word is used here in the Brundtland[11] sense of meaning that the well-being of future generations is being compromised by current consumption/production levels. Specifically, it is now commonly argued that *the* major threat to global food security is the substantial over-consumption and thus over-production of livestock products in more and more parts of the world. This has led to production systems which are out of balance with the environment and which in addition pose substantial questions about the acceptability of the welfare of these farmed animals.

The over-consumption of livestock products in many parts of the world itself can be damaging to human health, but more importantly it is a profound misuse of scarce resources. This is not only because of the meat itself but also due to the large amounts of cereals and other crops used for animal feed, which used resources which could have been directed to feed humans. The resulting pressure for agricultural production seriously damages climate, water quality and biodiversity and produces air pollution and other harms to human health.

It is not contested that current average levels of livestock protein consumption in Europe greatly exceeds the protein needs of most individuals in the population. In some Member States (MS), average meat consumption exceeds by up to 60% the recommended dietary levels[12]. The human body cannot make use of the excess protein except by metabolising it for energy. Therefore, the principal reason for criticising over-consumption of livestock products is not that it is damaging to human health *per se*, but that it is a deeply inefficient way of managing scarce earth resources of land and water to feed crops to animals to enable us to consume animal protein which is then simply burned for energy.

In addition, there are some direct negative human health impacts of over-consumption of certain livestock products. These concern the effects of excess fat, especially saturated fats[13] excess oestrogens and possible dangers from consumption of certain processed meats because of associated nitrite and N-nitroso compounds (NOCs), polycyclic aromatic hydrocarbons (PAHs) and heterocy-

11 This refers to Gro Harlem Brundtland, Chair of the World Commission on Environment and Development whose 1987 Report Our Common Future, whose central idea was that sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs.

12 See Chapter 3 in this report.

13 The relative causal contribution of animal fats versus sugar and high fructose corn syrup to the explosion of obesity, diabetes, hypertension, coronary heart disease and cancers (i.e. the so-called Western, non-communicable, diseases is a source of strong debate. See Taubes (2016) for a detailed account of this controversy in which he claims that there is weak evidence that livestock consumption has caused the explosion of these diseases, whilst there is far stronger reason and evidence that sucrose and fructose consumption have indeed brought about the massive rise in insulin resistance and metabolic syndrome which are the forerunners of these diseases. Whatever the conclusion of this debate, there can be no doubt that modern dietary intake wastefully includes more calories than are being expended for a large proportion of our populations.

clic amines (HCAs), many of which are produced when cooking the meat at high temperatures or curing it. If these human health considerations were not enough, equally concerning are the increasing incidence of anti-microbial resistance (AMR) in the human population towards antibiotics commonly used in human medicine, and the increasing incidence of zoonoses affecting the human population. More than nine million cases of gastrointestinal disease are estimated to occur annually in the EU from campylobacter and salmonella contamination (EFSA, 2011), although with a very low mortality rate. Other diseases are more difficult to transmit, such as avian flu or the recent Dutch goat disease, but associated mortality rates are much higher. There are multiple causes of AMR and one of them is the widespread use of antibiotics for farmed animals. This has included routine prophylactic use of antibiotics especially in poultry and pig production. These practices are now under scrutiny[14], and of course good animal welfare demands that sick farm animals are appropriately treated. However, the issue of AMR is now high in the list of concerns about what are routinely described as intensive, industrial or 'factory farming' livestock production systems. The sheer scale of the consumption of animal products and associated production has increased these concerns.

The environmental damage associated with the global livestock sector arises directly and indirectly, and it is manifest in Europe itself and in other parts of the world from which the EU imports livestock products and particularly animal feeds. The direct effects from the livestock themselves are: their GHG emissions especially methane (CH_4) and nitrous oxide (N_2O); the leakage of nutrients into the atmosphere and water from the animals and their manure; the demands on water and other scarce resources; and air pollution by ammonia (NH_3) and nitrogen oxides (NO_x) which are damaging to human health. It is therefore constantly asserted that livestock product consumption and production are inefficient, wasteful and leaky.

The indirect environmental damage of livestock production arises from pasture management and the cultivation of feed crops for the animals. It is estimated that 72% of EU agricultural land is used to feed farm animals (EEA, 2017a; Lesschen et al., 2011) (including grazing and feed).

14 In 2006 the EU banned antibiotic use for growth promotion and preventative antibiotic use in farms is now on its way to also being banned in the EU

This indirect damage appears as a share of the soil degradation and erosion, water pollution, GHG emissions (especially N_2O), habitat destruction, biodiversity loss and landscape change associated with the production of arable crops which are fed to livestock. Both the damage itself and the scientific evidence on the combined direct and indirect impacts of livestock product consumption and production in Europe, and indeed worldwide, have been steadily accumulating over several decades. At the global level, many reports have compiled evidence of the impacts of livestock on the environment and human health. This has led to calls for increased resource use efficiency in livestock production systems (Gerber and FAO, 2013; Steinfeld et al., 2006; Westhoek et al., 2016)and changes in consumption, specifically reduction of animal-based foods, particularly beef (Ranganathan et al., 2016; Wellesley et al., 2015). Complying with Climate Agreements, Paris COP21 and the Sustainable Development Goals (SDGs) will require changes in our current livestock sectors. At the Global Forum for Food and Agriculture held in Berlin in January 2018, agriculture ministers from 69 countries issued a communication calling for 'concerted action by all relevant stakeholders to engage in shaping livestock development to support the 2030 Agenda for Sustainable Development' and underlined the importance of 'a balanced consumption of food of animal origin for a healthy diet, health protection and the efficient use of resources'[15].

Naturally, as a major consuming and producing centre of global livestock with the associated animal genetics and production technologies, and as a growing exporter of these products and technologies, European livestock have been closely scrutinised. There is growing pressure to react. Much of the civil discourse ignores completely, or moves rapidly over, the positive contributions of livestock and the tone is overwhelmingly negative mentioning consumer health, environmental damage both in the EU and internationally, the contribution to climate change, and the over-use of limited and fragile resources. In addition, especially in Europe, there is a strong reaction concerning the scale, concentration and transport of livestock from the point of view of the welfare of farmed animals.

In short: four arguments are commonly offered to support livestock as a central part of our agricultural systems. These are (i) human nutrition, (ii) dietary preferences, (iii) pasture and crop by-product utilisation and the associated cultural landscape benefits of grazing areas, (iv) nutrient cycling. But seven concerns are expressed about current livestock consumption and production. The list is: (i) wasteful and dangerous over-consumption, (ii) climate harm, (iii) water and air pollution, (iv) biodiversity, (v) land use and soil degradation, (vi) anti-microbial resistance and zoonoses, and (vii) compromised animal welfare.

It is acknowledged immediately that the benefits of livestock are not absolutes. Humans can, and some do, exist on mostly vegetable diet, and some choose a life style with no livestock products at all i.e. vegans. Human preferences are not immutable nor unchanging. Natural grasslands do not have to be grazed by domesticated animals, they can revert to various forms of climax vegetation. Crop residues and by-products could be deployed into other uses than feeding animals (e.g. bio-materials and energy production). It has already been explained that livestock do not increase the available reactive nitrogen for agriculture but are quite wasteful net users of key nutrients. However, the benefits of livestock in rural areas, and of their products in daily lives, are real and deeply felt in our societies. They reflect the current tastes and preferences of humans today and we have built significant livelihoods, economic activity and culture around these animals and their products.

But the scale of the negative impacts of livestock suggest that livestock product consumption and production have developed beyond a point of acceptable balance. The livestock sector therefore must re-equilibrate. The underlying hypothesis of this report is that livestock have an enduring critical role to play in EU agriculture – but there is little, scientifically-based guidance on the scale of a better-balanced level of EU consumption and production and, within this, the balance between the main species, monogastrics and ruminants, and between production systems. The positive contributions of livestock certainly lead to the conclusion that in a more balanced agricultural system livestock still have a significant role to play. However, the negatives suggest that this might involve livestock populations and their geographical disposition considerably different from their current levels.

To express it another way, the report postulates the existence of a Safe Operating Space (SOS) for livestock in EU agriculture. Some non-trivial, lower levels of livestock are necessary for healthy and enjoyable European lifestyles, for utilising pastures thereby contributing to the social, cultural and environmental health of natural grazing areas. But equally there are upper limits to the total scale of livestock and certainly on their concentration over the landscape in the main production regions. There is a growing body of opinion both amongst the scientific and NGO communities suggesting that we are exceeding acceptable limits, in the EU and globally, on livestock consumption and production.

The research questions in this study are:

1 To investigate if a conceptual basis can be developed for the concept of a safe operating space for livestock.

15 Read the full communication here: http://www.gffa-berlin.de/en/gffa-kommunique-2018/

2 To suggest ways through which lower and upper bounds of this space might be quantified, even if approximately. The resources of the project do not stretch to large-scale empirical analysis. The intention is to build on existing research to suggest ways in which it might be possible to illuminate the scale and nature of EU consumption and production which could reasonably claim to be in the safe operating space.

3 On the presumption that the EU's SOS for livestock involves significant changes to reduce negative impacts of animal product consumption and production what is the range of actions necessary and possible to move livestock into a SOS, and what policies will be needed to bring about such adjustment?

The structure of the remainder of the report is therefore as follows.

Chapter 2 summarises the evidence that livestock consumption and production have become out of balance. It first documents the make-up, developments in, and global context of, EU consumption of livestock products and the corresponding structure, developments and context of EU production. It then examines the benefits and negative impacts of the livestock sector. The purpose is objectively, to summarise the main evidence for the positive and negative contributions of livestock indicating how they have come about and the scale of their impacts. All these benefits and impacts require careful exploration, especially since many of the studies focusing on them are not conclusive and further evidence is needed.

The idea of a Safe Operating Space (SOS) for livestock is investigated in **Chapter 3.** This is investigated in two stages. First it offers an analytical framework to identify a SOS by seeking to define lower and upper bounds of such a space in a way that that it might be possible to quantify. Second it explores data on some of the benefits and problems of livestock products to offer preliminary indications of what these lower and upper bounds might look like in relation to current levels of consumption and production.

Chapter 4 then considers the nature and scale of adjustments in consumption and production which are necessary to move the sector into its SOS. Two broad adjustment paths are examined. The first is to improve the resource efficiency and reduce leakage of livestock production systems by a range of means including new feeds, new technology and deconcentration of production. The second is adjust the level and balance of livestock product consumption, including reducing total protein consumption, substituting plant for animal protein, switching to novel protein sources such as insects or cultured protein. This chapter will review information on the potential for these adjustments to contribute to reaching the safe operating space.

The outcomes of Chapters 3 and 4 provide some preliminary answers to questions 1 to 3. It is not the intention that this study will describe the size and composition of a more balanced or optimal EU livestock sector, but it provides arguments on the required broad magnitude and directions of change to get to this position. Some of the issues can be satisfactorily analysed at EU or Member State level, but others, particularly the water and air pollution issues, may require a more locally defined spatial focus on the density of livestock and crop production.

The final chapter 5 discusses the policy framework and policy instruments which will be needed to bring about the scale of adaptation indicated. Having identified in chapters 3 and 4 the trajectory of change needed to bring greater balance to the livestock sector, chapter 5 will consider the public and private policy actions needed to move European livestock agriculture onto this more sustainable path. The outcome of chapter 5 are broad policy suggestions to enable a shift to a more balanced system: i.e. what signals, incentives and levers can be engaged to affect change.

A final consideration addressed in chapter 5 is the position of the EU in relation to international markets. EU livestock producers will, naturally, fear that any reduction in EU livestock production will be displaced by imports which would be a serious concern especially if they were associated with lower environmental or animal welfare credentials. Correspondingly, if adjustments in EU consumption are being made principally for environmental and animal welfare reasons, then it is important to consider the correct response if a reduction in EU consumption leads to more exports.

The holistic consideration of livestock attempted in this report inevitably embraces a wide range of technically complex, and difficult areas. It addresses: human health and diet, nutrient flows and their interactions with soil, water, air and biodiversity, climate change, animal health and anti-microbial resistance, and ethical issues concerning the appropriate treatment of animals. The authors do not claim expertise in all these areas, and the resources of this study were limited. The intention is therefore to offer what is hoped is a useful framework of analysis building on existing work and to tempt trans-disciplinary teams to follow-up these ideas.

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2. Consumption & production of EU livestock: benefits and negative impacts

2.1 Consumption, production, trade and trends

This chapter brings together the key data on the EU consumption and production of livestock products with an overview on the beneficial and negative effects of livestock on the environment and human health. The focus of this study is the EU so the scale and importance of livestock in the EU and its share of world trade in livestock and feed are juxtaposed against the global data where possible.

2.1.1. EU livestock consumption

Meat consumption. FAO statistics show EU citizens are supplied annually with an average of 81[16] kg of meat per capita per year of carcass weight, that correspond to approximately 51 kg/capita/yr of meat consumption[17]. This is twice the global average and makes the EU one of the

16 Faostat data 'Food supply: Livestock and Fish Primary Equivalent' for 2013

17 After excluding waste and parts of animals not eaten (see Chapter 3 for more information).

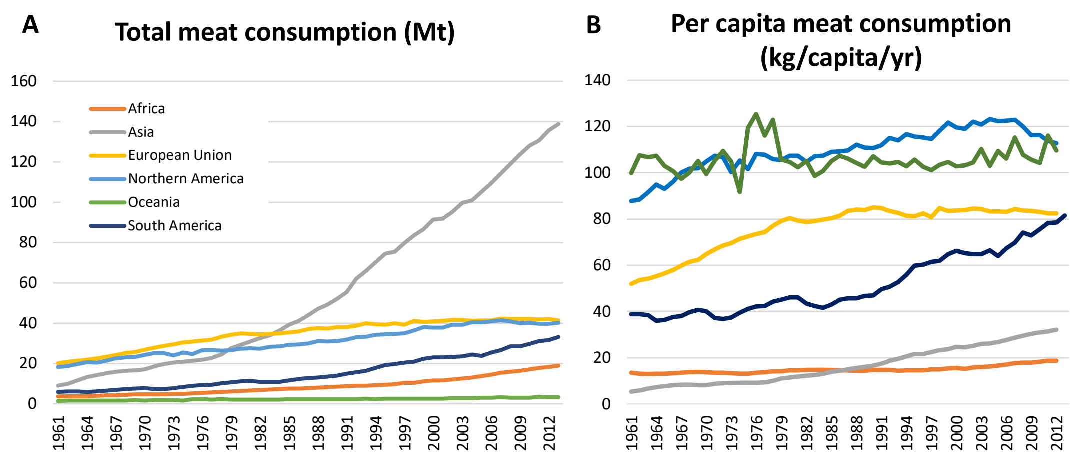

Figure 1. A) Total meat consumption, for selected world regions between 1961-2012; B) Per capita consumption, same regions between 1961-2012 (data source: own figure, data from FAOSTAT)

regions with the highest meat consumption rates in the world behind countries such as the USA, Australia, Argentina, New Zealand or Brazil, all have an average supply of >90 kg meat/capita/yr (Figure 1).

Meat represents 52% of the total protein intake in the EU27 (Westhoek et al., 2015). Almost half of the meat consumed in the EU comes from pigs, one third from chicken and the remaining from bovines, with a smaller contribution from sheep and goats and other meats. In relative terms, EU citizens, representing less than 7% of the global population, consume 18% of the world´s pigmeat, 12% of the world´s beef and veal, 12% of the world´s poultry meat and 8% of the world´s sheep and goat meat (OECD/FAO, 2017). Meat consumed by EU citizens has risen by 60% since the 1960s, led by a rapid expansion of poultry meat and pigmeat production that have become cheap sources of animal protein (Figure 2). Consumption may now be plateauing and for some meats, especially bovine, and some countries declining a little since 1991.

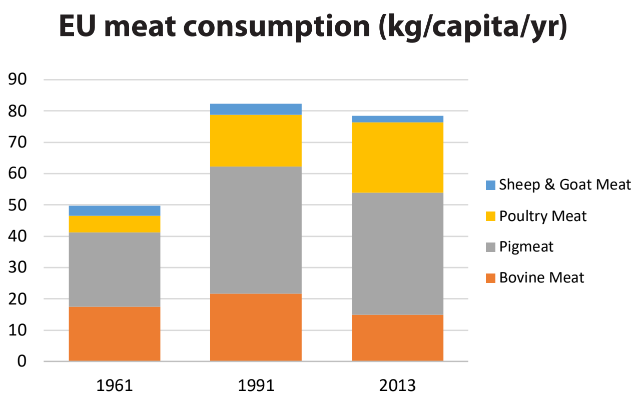

Figure 2. Evolution of meat consumption in the EU (1961, 1991, 2013) (data source: FAOSTAT)

In the EU, the increase in meat consumption during the 20th Century has not been homogeneous throughout its territory. It has been particularly dramatic for Mediterranean countries that have seen meat consumption increase three and four-fold and reach the levels of other European countries in just a few decades. But in the case of the three largest European countries (i.e. Germany, UK and France) total meat consumption levels were already close to the current average and increased only by 15-20% from 1961 to the 1990s. In addition to geographical differences, meat consumption patterns are quite depending on gender, age, occupation and social class. A study by the French think tank Terranova (Frioux et al., 2017) showed that men eat more meat than women, and that new generations are eating less meat than their parents. They also found that in France, people in jobs with high physical activity such as construction consume larger amounts of meat than those in the office-based professions. The study highlights that younger generations prefer processed meat over butcher meat and eat less butcher meat than previous generations. Contrary to earlier periods of history, wealthier people in the EU tend to consume less meat than those with lower incomes.

Dairy and egg consumption. The average EU citizen consumes 236 kg/capita/yr[18] of dairy products, making the EU population the third highest consumers in the world, after the USA and Australia who consume around 300 kg/capita/yr milk equivalent[19]. Between 1961 and 2014 the consumption of dairy (excluding butter) in the EU rose by 32% although with important differences between the MS. Northern countries such as Finland, Sweden and the Netherlands have consumption rates above 340 kg/capita/y while others in Eastern and Southern Europe do not reach the 200 kg/capita/yr mark. Based on milk equivalents, most milk is consumed in the form of cheese and fresh milk and to a lesser degree butter, cream and yogurt. In total, in 2016 EU citizens consumed 30 Mt of fresh milk, 9.3 Mt of cheese, 8 Mt of yogurt, 2.6 Mt of cream and 2.2 Mt of butter. This represented a decrease in fresh milk compared to 2006 levels, but a moderate increase for the rest of the products. Cheese consumption has experienced the largest growth, partly linked to its use as an ingredient in a large number of prepared foods such as pizzas and sandwiches, while cream and other dairy products less so. Butter consumption has declined following many years of dietary advice. Egg consumption in the EU is 12 kg/capita/yr of eggs, compared to the global average of 9 kg /cap/yr.

Future consumption trends. The outlook for future EU livestock product consumption is complex, and of course differs between the MS. In general, projections suggest that the consumption of dairy products, in the form of cheese and butter driven by their use in processed and bakery products, will continue to increase over the coming decades, although at lower rates than in the past. Chicken consumption, as the most consistent, convenient and quickest to prepare and cook is also expected to increase. The consumption rates of other meats are projected to stagnate or slowly fall (European Commission, 2017a). In general, the consumption of butcher meat is decreasing while that of processed meat is increasing.

Forecasts for 2030 show few changes at the EU level, however, a shift towards less meat and maybe even dairy intake could take place in the coming decades. Vegetarianism and veganism are not mainstream in the EU. And even in countries with the highest proportion of citizens expressing such choices, the percentage of the population following them is less than 10% (Chemnitz and Becheva, 2014). However, there is a trend towards ´part

18 FAO supply in milk equivalent for 2013
19 FAOSTAT supply data with applied correction factors for waste for the period 2007-2013 (see Chapter 3 part on National Recommended Diets).

time vegetarians´, or ´flexitarians´, that is, people consuming meat occasionally. Many initiatives exist across the EU over the last decade to encourage citizens to eat more vegetables and reduce meat intake. This is now increasingly argued on grounds of environmental impact and animal welfare, as much as on health grounds alone. The dietary advice found in nationally recommended diets in most EU Member States specifies consumption levels for meat, and sometimes specifically red meat and animal fats, which are well below current consumption levels[20].

At the global level, what has alarmed informed opinion, led by the FAO's landmark report, Livestock's Long Shadow (Steinfeld et al., 2006) are the potential consequences of the rest of the world following the same development path as Europe and North America as they enjoy economic growth. Figure 1 shows the growth in meat consumption in total and per head since 1961. It is the prospect of Asian, and subsequently African, meat consumption rates closing the gap with those observed in Europe and North America which drives towards the conclusions that this may be unsustainable.

2.1.2. EU livestock production

The doubling of livestock product consumption in the EU since the mid-20th century was made possible by the corresponding increase in EU production. The increase in livestock numbers and production during this period was enabled by significant technological and structural change in livestock farming systems encouraged by supportive agricultural and protective trade policy. This allowed many livestock farms to evolve from small farms to large commercial businesses. The EU has also become a significant livestock product exporter, especially of dairy and a significant importer of animal feed.

Over the course of recent decades, the EU has seen a steady trend towards specialisation, business enlargement and intensification. Total farm numbers have declined over a long period. Even recently, between 2005 and 2013, farm numbers fell by an average of 3.7% per annum while production continued to rise[21]. The importance of very large farms[22] is such that, in 2013, 6.3% of farms in the EU produced 71.4% of the standard agricultural output. Livestock production is no exception to the concentration trend and 72% of the EU27 livestock units[23] (LSU) are found on very large farms. Farm enlargement has come about through measures to improve labour productivity like new housing systems and forage management. These and other developments in genetics and health care have led to higher output per animal and lower prices. These, in turn, induce further innovation to improve labour productivity (Cochrane's treadmill). The feed input for livestock has partly shifted from forage and food by-products to more scientifically-formulated and nutrient-denser crops, oilseed cakes and other crop by-products. Real prices for feed grain and high protein oilseed cake, especially soya, and energy declined until comparatively recently and contributed to growing supply and low prices of meat and livestock products. Most EU meat and dairy production is based on EU grown feed, but the EU relies heavily on imports to satisfy its protein requirements for feed. Up to 70% of high quality protein feed is imported from outside its borders (Bouxin, 2017). Most EU livestock production is domestically consumed; net exports constitute less than 10% of the total production. However, due to the large production volume, the EU is one of the largest exporters of dairy products and pigmeat globally.

Meat production. In 2017, the EU produced 47 million tons of meat made up of: 50% pigmeat, 31% poultry meat, 17% bovine meat, and 2% sheep and goat meat[24]. This meat output made the EU the second largest meat producer in the world next to the USA, with 14% of global production, and after China, ranking first with 28% of global production[25]. Globally, the development of intensive livestock production, especially of the monogastrics, pigs and poultry, enabled the great increase in meat and livestock production in the second half of the 20th century. Global meat production quadrupled between 1961 and 2010, milk production (excluding butter) more than doubled, and egg production increased more than fourfold (HLPE, 2016) (Figures 3, 4). In the EU, this resulted in meat production doubling between the 1960s and 1990s, from 20 Mt to 40 Mt per year. The global increase has been more pronounced, rising from roughly 70 Mt of meat in the 1960s up to 320 Mt in 2014 (Figures 3 and 4).

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20 The National Dietary Recommendations are explored in more detail in Chapter 3.
21 Farm structure survey data from Eurostat
22 Very large farms are those with an economic size above 100,000 euros according to Eurostat.
23 Livestock units are reference units of measure for livestock numbers. 1 LSU is the equivalent of a grazing dairy cow that produces 3000 L of milk annually without additional feed (Eurostat).

24 Although very marginal, sheep and goat meat play an important role in a few MS.
25 From Eurostat´s milk and meat production in 2013.

Evolution of global meat production 1961-2014 (Mt)

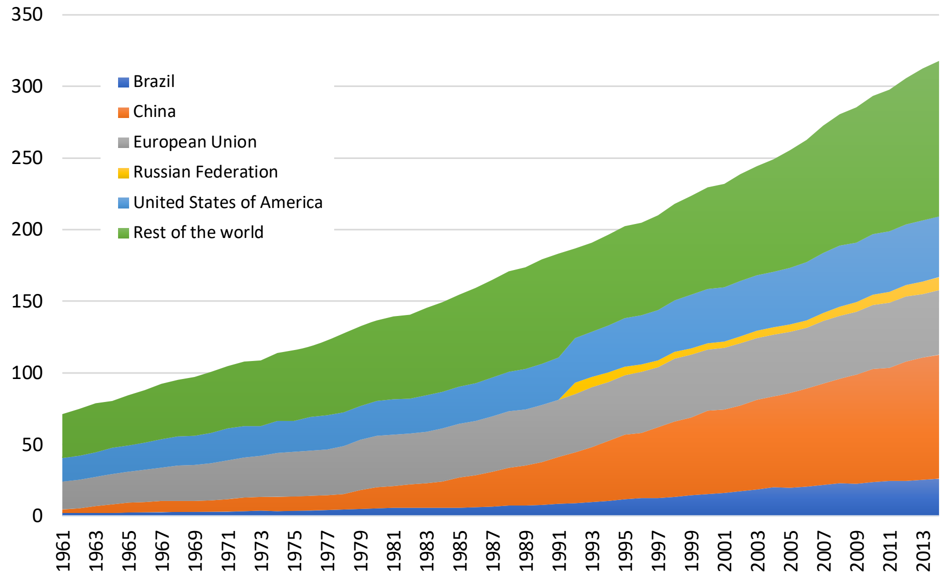

Figure 3. Meat production in the world by region 1961-2013 (data source: FAOSTAT)

This general increase in meat production can be attributed to a rise in livestock numbers until the 1990s. In the EU, improvements in efficiency, particularly through breeding and nutrition, and specialisation as livestock on mixed farms disappeared, have enabled a continued but slower growth in pig and poultry meat production despite a decline in livestock numbers since 1990. In 2017, the EU28 produced 23.7 Mt of pigmeat making the EU the second largest producer globally after China, with 20% of world production (European Commission, 2017a). EU poultry meat production has risen to 8 billion poultry head in 2015 (representing about 16 birds per head of hu-

Evolution of meat production in the EU (1961-2014 (Mt)

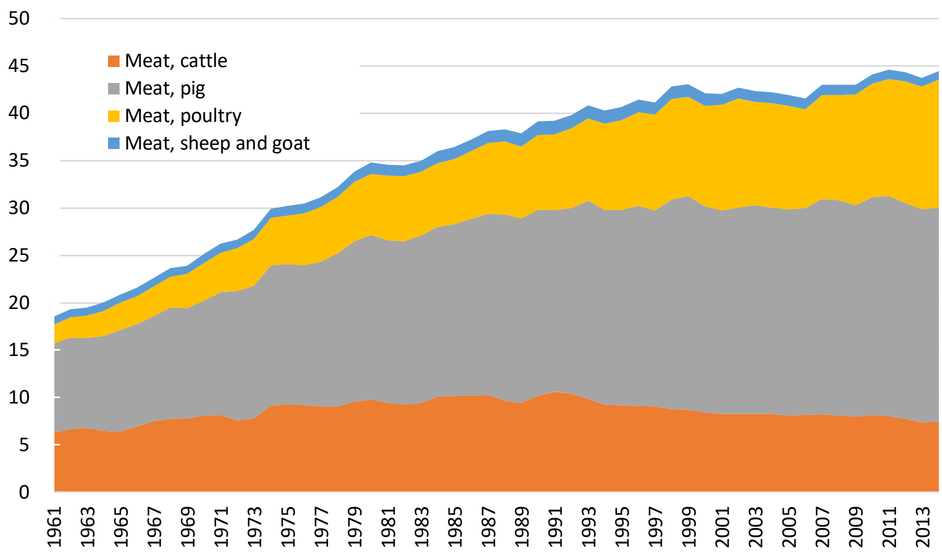

Figure 4. Meat production in the EU28 by species, 1961-2013 (data source: Eurostat)

man population!). The pattern is different for the largely grazing-based bovine and ovine meat sectors. They have seen slower structural change, they are less able to intensify, and animal numbers and production in the EU have followed a downward trend since the early 1990s[26].

Dairy and egg production. The EU28 produces around 160 Mt of milk, 97% of which is cow's milk produced by a herd of 23 million cows. Three percent of EU milk production in 2016 was organic. Milk production increased 30% between 1960 and the introduction of milk quotas in 1984, and has risen by 24% over the last 15 years, with a significant increase since the abolition of milk quotas in 2015. Less than 10% of milk is used on farms, the rest is delivered to dairies and processed into drinking milk and manufactured products. Milk components can be partitioned in many ways to produce a wide and increasing array of dairy products. 37% of the whole milk delivered to dairies is used to produce cheese, 30% to produce butter and yellow products, 13% cream and only 11% drinking milk[27]. These EU-wide figures conceal that the utilisation of milk and milk products differs considerably between the MS.

According to the EU Milk Market Observatory, there are large differences in milk yields between MS; averages range between 1200 kg and 9300 kg per lactation. The average milk yield per cow in the EU has been increasing over the last decades, reaching 6941 kg of milk in 2016, and it is expected to continue growing accompanied by further reductions in cow numbers (European Commission, 2017a). The high intensity of EU production is illustrated by the global average milk production per cow of only around 2000 kg. The EU dairy industry has about 600,000 dairy farms and 12,000 processing facilities, France and Germany are the largest producing countries.

The EU produces about 7 Mt of eggs annually. The production multiplied by 1.6 between the 1960s and 2014, while global production increased six-fold.

Other livestock products. In addition to meat (which includes some edible offal), dairy and eggs a significant proportion of the slaughtered weight of farm animals (42% of beef, 34% of pigs and 25% of poultry) is not directly consumed by humans. These materials are separated, some are used directly and others rendered and processed into bone meal, blood products, fats, tallow, hides, skins and many other products. There is also considerable international trade, mostly exports, of some parts not customarily consumed in Europe but enjoyed in other cultures. Resulting from these is a wide range of food and non-food products including cooking fats, oils and grease, pet foods and biofuel.

26 FAOSTAT database 'live animals'
27 Eurostat database, 'milk and milk product statistics'

Livestock trade. There is some international trade in live animals[28], and certainly breeding animals and livestock genetics, but most trade is in processed products. The major part of EU meat and dairy production is domestically consumed, and exports account generally for 10% or less of the production. There are a few exceptions to this, mainly dairy products. It is expected that by 2026, the EU may be supplying 40% of the world cheese exports. Brazil is the largest source of imports for beef (40%) and poultry (50%) into the EU[29]. The EU has an 88% self-supply of sheepmeat and the major source of sheep meat imports is New Zealand. Almost half of these imports go to the UK. Although the EU is still a major market for meat and livestock products, there is much more dynamic growth elsewhere in the world, suggesting that continued expansion of EU production implies growth in exports. The EU exports more meat than it imports. The EU is a principal exporter of pig products to Asia especially China. Exports of beef and veal are more widely distributed including to the Middle East. For poultry meat, half of the exports are shared between South Africa, Benin, Hong Kong, Saudi Arabia and Ukraine. EU livestock product exports are significant and have grown, despite the EU being a relatively high cost producer protected by import tariffs and supportive domestic policy. Much of its trade is based on its credentials for high quality products, good marketing and branding, and in turn on stringent public health, traceability, environmental and animal welfare regulation.

Livestock numbers and farming systems. Compared to the human population of 500 million, the EU has around 350 million farm mammals (cattle, pigs, sheep and goats) and around 1.6 billion poultry[30]. Whereas poultry numbers have experienced a continuous increase over the last half century, the number of mammals experienced first a period of expansion (1961-1990) followed by a period of reduction in numbers (1990-2014) and today, the total number of farm mammals is not substantially different than it was fifty years ago. This total, however, hides the fact that there are 55% more pigs but 14% less cattle and 17% less sheep than in the 1960s. Goat numbers, very low and marginal within the EU in general but significant in some MS, have remained relatively stable.

Modern livestock farming produces considerably more meat and livestock product than in the past, and does so, with a smaller livestock population of mammals. Trends in farm structure indicate that both spatial agglomeration and farm size are increasing, while farm mammal numbers continue to decline. This means that the livestock

28 Which is vulnerable to concerns about the welfare of live farm animals in transport.
29 EU Market situation for poultry in 2017 and Beef &Veal market situation in 2018 from https://ec.europa.eu/agriculture/
30 Note that the 8 billion poultry head per year cited above is explained by the turnover of broilers which typically grow to slaughter weight in 42-60 days.

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sector is constituted of fewer and larger farms every year[31]. These large farms are highly specialised, not only for animal type but also for specific stages of the breeding and fattening process (e.g. suckler beef, beef finishers, farrowers, weaner producers, pig fatteners, finishers), with animals from a very limited number of breeds which have been bred for high productivity measured as feed-efficient, fast live weight gain of saleable product, milk yield, numbers of lambs, or eggs per bird per day. They are also well-adapted to available feeds. On the contrary, smaller livestock farms tend to practice mixed livestock or mixed crop-livestock systems[32]. To illustrate the scale of these developments, total standard gross margin of specialised livestock holdings has doubled over the last 20 years, and the importance of mixed livestock farms has fallen. A large majority, 82%, of livestock in the EU are managed in specialised farms and 16% in mixed farming systems[33]. This specialisation is also accompanied by a reduction in the hectares of utilised area in livestock farms.

Livestock farming has become much more geographically concentrated and disassociated from crop production. Most farm mammals and poultry in the EU are concentrated in just a handful of countries, and in specific regions within these countries. Four countries; Germany, France, Spain and the UK have 54% of the cattle, 50% of the pigs and 54% of the sheep and goats in the EU28.

Feed use. Traditionally, farm animals were fed with grass, waste and by-products because cereals were too expensive to be used on animals (Steinfeld et al., 2006). Today, farm animals consume 57% of the cereals grown in the EU, grazing is on a downward trend in many EU countries and the feed sector relies on imports to meet market demands for protein feed. Feed is the major cost factor for the livestock farmers. The extreme case is poultry for which feed can represent up to 85% of the production costs. Feed represents around two thirds of the production costs for pigs (AHDB, 2016) and 50% for cattle. Farm animals in the EU27 consume an estimated 481 million tons of feed a year, of which 233 Mt is roughage, 156 Mt is compound feed, 52 Mt of cereals grown on farm and other purchased feed materials (Bouxin, 2017). Put in another way, 3 kg of feed are used daily per EU citizen, which is then converted into 0.1 kg of meat and 0.8 kg of milk (Westhoek et al., 2011). Feed conversion efficiencies are very different between the species. For each 100 calories fed to livestock, less than one fifth remain available for human nutrition in meat (Lundqvist et al., 2008; Nellemann et al., 2009). The value depends on the product considered. Feeding 100 calories of grain would on average yield 12 calories in chicken, 10 in pork and just 3 of beef (Cassidy et al., 2013). These values are higher for milk,

31 Between 2003 and 2010 livestock farm numbers were reduced by 35%, while farms in general were reduced by 20% (Eurostat)
32 Farm Structure Survey in Eurostat
33 From Eurostat's 'Agri-environmental indicator specialisation' (2013 data)

40 calories, and eggs, 22 calories, but remain nonetheless considerably lower than consuming the grain directly[34]. Monogastrics are clearly more efficient meat producers than ruminants on a per calorie or per protein basis, although it is critical to note that ruminants convert large amounts of feed inedible to humans – up to 83% of total feed proteins in the case of grass-fed beef (Laisse et al., 2017). Another way of depicting the sheer inefficiency of providing protein for humans via livestock is indicated by estimates that the land needed to produce one kg of vegetal protein is one-third of that needed to produce 1 kg of pigmeat protein or one fifth of that to produce 1 kg of beef protein (European Commission, 2012).

The EU livestock sector utilises 22% of the globally produced compound feed (Bouxin, 2017). Compound feed is comprised mainly of cereals (48%), oilseed meals and cakes (28%) and by-products from the food industry (11%) (EIP-AGRI Focus Group: Protein Crops, 2014). 35% of the compound feed produced in the EU27 is fed to poultry and laying hens, 32% to pigs and 28% to cattle.

The volume and sources of protein for the livestock sector have become a much-discussed subject[35]. Livestock derive their protein needs from grass and conserved forage, from specific protein-rich crops such as wheat, barley, maize, oilseeds and pulses and from compound feeds including by-products such as meals and cakes from soyabean, rapeseed and sunflower. 70% of the protein-rich feed derives from cereals (40%) and soyabean meal (29%) (FEFAC, 2017). But while the EU is 91% self-sufficient in cereal production for feed, it is only 5% self-sufficient for soyabean meal, and 38% if we include meals and cakes from all oilseeds. 60% of the protein meals used in the EU come mostly from imported soya meal and soybean and with some from palm products (European Commission, 2017a). Consequently, the EU is one of the largest soya importers in the world[36]. Soya is a versatile and high quality source of protein for livestock development and growth and its use has greatly helped improve feed conversion efficiency in pig and poultry production. Cereal and soya consumption in the form of compound feed is heavily utilised by the large and intensive pig and poultry sectors: 73% of the soya meal is used in pigs and poultry (Friends of the Earth Netherlands, 2008). The dairy sector is the second largest consumer of cereals and protein crops to maintain high milk yields, and specialist beef fatteners are the third important consumers of these compound feeds (Bouxin, 2017). However, EU soya imports attract several criticisms. First, there is a strong strand of opinion which questions reliance on imports of feed ingredients. This speaks of the 'protein deficit' and implies that the EU should aim to be more self-reliant. Second, this tends to be amplified because much of the soya is exported by Brazil and is assumed to have a poor environmental footprint and direct association with rain forest destruction. Third, an increasing share of soya production from the Americas, both North and South, is based on genetically modified cultivars which are controversial in Europe. There is no doubt that there have been serious environmental spill-overs associated with the expansion of Brazilian agriculture. How to scale the current environmental footprint of produce from different regions of the world is a contested area.

Prospects for livestock production. At the heart of livestock discussions lies the issue of how the sector will evolve and what its contribution to the global food demand will and should be. Conventional assumptions, based on current trends and policies, are that population and income growth worldwide will drive continued growth in livestock product consumption as more people make the dietary transition which has generally accompanied economic development. The production of meat and dairy products is expected to grow in step to enable this increase in total consumption. Both the OECD and the FAO project large increases in meat production worldwide, with 75% of the growth to take place in developing countries (OECD/FAO, 2017). There is now an active debate whether the environmental, health and animal welfare impacts of this growth in livestock consumption are acceptable, and indeed feasible. The situation in the EU is expected to be very different. Projections by the European Commission for the period 2017-2030 indicate that the EU livestock sector, already very large, is unlikely to expand substantially. Most of any increase will be concentrated in poultry production, with further increase too in sheep meat production and in dairy output.

2.2 Livestock´s impacts

Livestock's impacts are addressed under nine headings: (i) human health and nutrition; (ii) utilisation of pasture, crop by-products and residues; (iii) culture and livelihoods; (iv) climate harm, (v)nutrient cycles, (vi) biodiversity, (vii) land use and soil degradation, (viii) Anti-Microbial Resistance (AMR) and zoonoses, and (ix) compromised animal welfare. Many of these impacts have both a positive and a negative component and these are discussed in the sections below.

34 This demonstrates the fundamental inefficiency of deriving calories from livestock products. Of course the prime purpose of livestock products is to supply protein. The significance of this is examined in section 2.2

35 The questioning of protein imports into Europe is part of a wider questioning of liberal trade which is in the ascendency as populists exploit the dissatisfactions of those who feel they have not shared in the benefits of globalisation. The tendency for such argument to drift towards mercantilism and protectionism is just as stoutly resisted by economists as it ever has been. How this will resolve for the so-called EU protein deficit is unclear.

36 The EU imports 35 Mt (97%) of soyabean and soyameal, representing almost 20% of globally traded soyabean and soyameal (FEFAC et al. 2105)

2.2.1. Human health and nutrition

Livestock products have a beneficial nutritional profile for human health and have represented a highly valuable food source for human nutrition for centuries. However, following the large increase in consumption levels detailed above, the overall impact on human health has been questioned.

Humans eat livestock products because they like them and they provide valuable nutrients. In all EU countries livestock products are included in national dietary recommendations as a source of protein, vitamins, minerals and fats. Animal protein is often seen as higher quality protein than plant protein because it contains a wider profile of amino acids, although this varies between animal species and different parts of the animal. For the same total weight, high quality muscle meat contains a higher proportion of protein than pulses, and all the essential amino-acids. Specific plants have specific narrower range of amino-acids so a balanced diet needs combinations of plants. Red meat, especially beef, contains three times the iron content found in white meat. The iron found in meat is heme iron, easily absorbed by the human body, whereas the iron found in plants is non-heme iron and must be converted before absorption. Other nutritional attributes of livestock are the presence of fatty acids, calcium and vitamins D and B-12. The fatty acid composition in meat is generally claimed to be better in grass-fed beef compared to grain-fed beef (Daley et al., 2010).

Before moving to negative health effects, it is acknowledged that it has only taken a single succinct paragraph to summarise the massive enjoyment and nutritional benefit humans derive from consuming livestock products, yet the negative effects will occupy the next ten paragraphs! This does not seem to do justice to their relative contributions. It can perhaps be explained that the benefits are easily sensed by those who consume these products but the evidence on the harmful impacts is complex and less well known and understood.

Over time a large range of negative impacts for human health arising from what is now seen as systematic over-consumption of such products has been recognized[37]. An early contribution, in the 1960s, was the publication of several cross-country comparison studies concerned with the rising levels of over-weight and obesity, and increasing diabetes and coronary heart disease. Animal fat was implicated in these developments. Today, despite the enormous amount written on these conditions and their links to changing diets, and lifestyles, it is still difficult to reach a balanced understanding of their overall impacts on human health. This uncertainty is explained by many factors. A key explanation is the difficulty of arranging scientifically controlled experiments in humans with sufficiently large numbers, which persist over long-enough periods, and where factors besides livestock product consumption levels are controlled. A further factor is that the associations between any food group and health can have serious economic implications for very large commercial interests, so this adds another dimension of uncertainty to objective assessment. And if these uncertainties were not enough, the challenge of distilling well-based truth from opinion is compounded by the staggering volume of popular food writing and social commentary on eating, health, lifestyle and environment in print, broadcast and social media in which uncertainties are swept aside and scientific verification counts for little. Notwithstanding these uncertainties, many studies have compiled enough evidence to connect certain meat consumption patterns with raised levels of development of cardiovascular disease (CVD) and certain types of cancer, and also the benefits of milk and dairy products on bone health have been called into question[38]. Each of these complex issues is considered briefly.

The connection between consumption of livestock products and CVD is complex and highly uncertain, this explains why dietary advice tends to be broad and about getting the right balance, "everything in moderation" is a common phrase. A key difficultly lies in separating the impact of livestock product consumption on health from that of multiple other factors such as other foods consumed at the same time, exercise and genetics. For many years, dietary recommendations to reduce the risk of CVD focused on lowering the intake of saturated fats and avoidance of rising cholesterol levels. These assumptions were based on relatively few long-term studies[39] showing that high serum cholesterol and blood pressure together with other factors such as diabetes and smoking are universal risk factors for coronary heart disease. However, cause and effect here has not been satisfactorily resolved given the absence of convincing evidence in controlled experiments that reducing consumption of animal products reduces the incidence of these diseases. Nonetheless dietary advice since the 1970s world-wide has focussed responsibility for the rise in obesity, diabetes and CVD on dietary fat, especially saturated fat. It has advocated reduction in the proportion of energy derived from animal products particularly those with high saturated fats. Despite this advice, and some evidence of declining consumption of some dairy products and red meat, there has been no reduction in obesity, and

37 It is useful to make a distinction between over-consumption of livestock products by individuals and the impact on their health, and over-consumption by households which results in uneaten and thus wasted food which constitutes a grossly inefficient use of all the resources used to produce and distribute such products.

38 See section on 'calcium, bone fracture and osteoporosis'.

39 Cholesterol as a risk factor was first introduced by two large scale studies, that of Ancel Keys (1904-2004), the "seven country study" launched in 1958 and 'The Framingham Study' by Dawber in 1980.

the suite of non-communicable diseases including CVD, indeed the reverse. More recently an explanation has been offered that in addition to the rise in consumption of livestock products documented in section 2.1 above, there has been an equal rise during the 20th Century in the consumption of sugar. There is mounting evidence of how sugars, particularly sucrose and fructose can precipitate metabolic syndrome and insulin resistance which shows up as over-weight, elevated blood pressure and early symptoms of diabetes: all are strong indicators of CVD. A recent powerful exposition of this controversy is provided by Taube (2016) in his 'Case against Sugar'[40].

Turning to carcinogenic effects, associations have been found between processed meat (i.e. cured, smoked, fermented or salted), red meat and colorectal cancer. The WHO estimates that globally, 34,000 deaths per year are attributable to cancer caused by processed meat consumption, while 50,000 deaths are attributable to cancer caused by consumption of red meat[41]. Despite the difficulty in establishing a direct link between cancer and meat consumption, these numbers are low compared to the approximately 2 million cancer deaths a year due to tobacco smoking.[42] A recent reference on the carcinogenic effect of meat is the 2015 IARC (International Agency for Research on Cancer - WHO) report that brought together 22 experts and assembled all relevant literature (800 studies over the last 20 years) to determine the carcinogenicity of the consumption of red and processed meat on humans. The monograph placed processed meat in IARC's Group 1 "Carcinogenic to humans" (15 out of 22 experts voting in favour), meaning it is ranked as high as tobacco smoking, ethanol in alcoholic beverages, sunshine and asbestos exposure, because it's considered that there is "sufficient evidence" that the consumption of processed meat causes colorectal cancer.

The compounds that produce the carcinogenic effect are nitrite and N-nitroso compounds (NOCs), polycyclic aromatic hydrocarbons (PAHs) and heterocyclic amines (HCAs). Many of these are produced when cooking the meat at high temperatures or curing it. Another key compound seems to be 'haem', produced when N-nitroso compounds are decomposed and can cause cell destruction in the bowel. In the IARC report, the experts concluded that a 50 g portion of processed meat eaten daily increases the risk of colorectal cancer by 18%" (i.e. if the background risk is around 5% it is raised to 6%). Although the outcome of the IARC monograph was received as "not surprising", and "a confirmation of what was already known" by academics, these results exemplify the difficulty of correct interpretation and providing appropriate dietary advice.

Calcium intake is necessary to maintain bone health, reduce the risk of osteoporosis and fracture. Calcium is obtained through milk and dairy products and from leafy dark green vegetables. Milk has the highest concentration of absorbable calcium of all food products we consume but the role of milk and dairy in preventing hip fracture remains controversial. Most countries include milk and dairy in their dietary guidelines encouraging consumption to keep our bones healthy. Some countries also have separate recommendations for children and pregnant women. However, over the past decade several studies have suggested that healthy bones and milk consumption may not necessarily go hand by hand. Overall, however, the relationship between milk and dairy consumption and disease remains inconclusive (Weaver, 2014).

Given that public health measures and modern medicine have massively reduced if not eliminated the major communicable diseases it is perhaps unsurprising, even inevitable, that major causes of death now are the impacts of our sedentary lifestyles and our tendency to over-consume many types of food. There is scientific agreement that increasingly in developed economies, and in many transition and developing economies too, humans are systematically consuming more calories and protein daily than expended in body maintenance and activity leading to over-weight and obesity. From the above brief review of the vast amount of literature on diet and health it seems clear that there are negative impacts on health of current consumption levels of livestock products.

What is not in doubt is that the over-consumption of livestock products by individuals and households is extremely wasteful of scarce food production resources. This waste is compounded as the other impacts of the expansion of livestock on environment and animal welfare are considered. What is the scale of the over consumption of protein? On average, EU citizens consume 104g of protein daily, 58% of which in the form of animal protein[43]. The remaining 42% is mostly from cereals and smaller percentages from vegetables and pulses. The global average is the other way around; 60% plant-based protein and 40% animal-based protein. Recommended dietary levels of protein intake are suggested by the WHO and the EFSA. The WHO recommends 50g of daily protein intake without specifying the source of the protein. The Recommended Dietary Allowance (RDA) for protein suggested by EFSA is 0.83 grams of protein per kilogram of body weight per day, which equates to between 67 g

40 It is interesting that there is a powerful strand of opinion that the predominant focus on excessive animal fats in western diets for the last almost 5 decades has been misplaced and has allowed sugar, especially sucrose and fructose, to escape sufficient attention with catastrophic impacts on human health.

41 Red meat is meat that is red when raw. This includes meat from beef, pork, lamb and horse. Most processed meat (where processed refers to curing, smoking and drying) is red meat, not much poultry meat is processed in these ways.

42 See: http://www.who.int/news-room/fact-sheets/detail/cancer

43 FAOSTAT dataset for 2014

and 114 g per day for men and between 59 g and 102 g per day for women. Current levels of protein intake in Europe are considerably above these recommended values. The recommended values are established based on the 'nitrogen balance' approach that measures the difference between nitrogen intake through food and the amount of nitrogen excreted, defining a minimum intake that will allow the body to be in balance.

RDAs have changed since they were first set in the 1950s. Reports suggesting that a reduction in the consumption of meat would benefit the health of EU population are based on the current levels of protein and saturated fat consumption which are well above those recommended by national and international health organisations[44]. Considering that more than 40% of the current protein intake in the EU comes from products other than meat and livestock products, meat consumption is not necessary to reach the required levels of protein replacement in human bodies[45].

A way of establishing a safe level of protein intake is therefore to consider the capacity of the liver to convert proteins into urea. Its capacity can be exceeded when proteins represent more than 35% of the energy intake of a diet (Bilsborough and Mann, 2006). A reasonable question then is what does the body do with excess protein intake? Such protein cannot be stored in the body. So, it is broken down into its constituent amino acids that are 'deaminated', that is lose their amino group, and transformed other molecules that can be oxidized i.e. converted into energy, or recycled in the human body. In the process, ammonium is formed and since it's toxic, it is directly converted into urea, which is the body's mechanism to eliminate excess nitrogen.

In conclusion, eating excess livestock protein is not necessarily bad for human health but represents an extremely inefficient use of nutrients if much of the expensively produced protein in human diets is, after all, burned for energy. It would have been orders of magnitude more efficient to have eaten plant energy sources rather than putting this plant material through animals first to be converted into animal protein.

2.2.2. Utilisation of pasture, by-products and crop residues

A unique, contribution offered by certain farmed livestock is that they can utilise plant material which is simply inedible and indigestible for humans, principally grasslands. This contribution is offered by ruminants; cattle, sheep and

44 Westhoek et al., 2015 suggests that the current average EU intake of protein is 70% higher than the recommended intake and that of saturated fats is 42% than recommended
45 Even human breast milk (to feed newborns) contains lower levels of protein, fat and sodium vs those of cow milk (Ballard and Morrow, 2013).

goats whose multi-chambered stomachs contain the bacterial mix and enzymes to digest cellulosic material from grass, conserved forage (hay and silage) and leafy material from trees and shrubs. Such herbivores thereby provide a human-edible source of proteins, carbohydrate, fats and micronutrients in the form of meat and milk. This facility potentially opens-up for food production purposes considerable areas of land which is otherwise unavailable for crop production because of its slope, altitude, unsuitable soils or climate (which can be too hot or cold, too wet or dry for cropping). Globally it is estimated that 86% of the livestock feed intake is made of feed materials that are not eaten by humans (Mottet et al., 2017), although in the EU the value is much lower. In the EU, 72% of agricultural land is used to produce the feed for meat and dairy products. Half of that corresponds to grassland and intensive grass production for ruminants while the other half represents the cropland area needed to produce feed.

Cattle and sheep can be raised entirely on such grasslands[46]. Climatic conditions and thus grass growth and the length of the grazing season vary greatly around the EU. Conservation of herbage as hay and silage provide winter feeding when grazing is not possible. In some EU Member States, e.g. Ireland, the mild climate allows grass growth and thus livestock production throughout the year. Livestock play a very important role in areas of permanent pastures where the land cannot be ploughed or cultivated in providing food and, in the process, providing employment and economic activity. This is especially so in areas of rough grazing which have few possible alternative activities. In such areas winter feed is generally provided by conserved pastures or by moving animals, often down the mountain or hill, to more fertile soils which can provide other winter forage, legumes or root crops. These traditional and usually extensive livestock farming systems use animal breeds suited to the local conditions, growth rates are typically slow, and milk yields are low. Improved pasture management, and breeding allowed some increases in productivity of such areas, but the experience has been that economic and environmental limits to such 'improvements' are often quickly reached.

The importance of grassland to support livestock has been decreasing over time. A decline in permanent grassland area in the EU28 over the last thirty years in favour of development or conversion to forest and arable land has been observed, with decreases up to 30% in countries such as France, the Netherlands or Belgium (Peyraud and Peeters, 2016). This is particularly problematic when considering that in addition to supplying feed for grazing livestock, pasture-based livestock systems can deliver valued ecosystem services to society. Some of these are environmental such as the maintaining soil fertility, pollination, preventing fires and contributing to biological control, while others are of a social and cultural dimension; i.e. the preservation of agricultural landscapes, cultural heritage and encouraging rural tourism (Bernués, 2016). These pastures are often found in High Nature Value (HNV) farming areas[47] which have an important contribution in maintaining biodiversity associated with grazing systems. The role of livestock in pastures is especially important in mountainous areas. In the Alps, dual purpose cattle breeds, for milk and meat production, were traditionally kept inside barns during winter and left to graze on high-pastures during summer. Strong reductions in cattle herds over the last decades and a strong preference for highly-productive and specialised breeds has caused pasture degradation and forest re-growth with impacts on cultural and aesthetic values, biodiversity and fire prevention and other ecosystem services such as water provision (Battaglini et al., 2014). A similar situation is taking place in Mediterranean areas where low input pasture based farming systems that provided crucial ecosystem services are being abandoned in favour of intensified production in more favourable areas that is also more dependent on off farm inputs (Bernués et al., 2011). Other pasture ecosystems have developed in combination with human transformation. This is the case of sylvo-pastoral systems such as dehesas in Spain and montados in Portugal that are of high ecological value. These systems, occupying 3.7 million ha in the Iberian Peninsula and created mostly during the 19th and 20th centuries, still play a crucial role in regional economies but some are currently threatened by abandonment and intensification[48].

In addition to these permanent grasslands which are generally found on more marginal quality land, a considerable amount of ruminant production, beef, milk and sheep production, takes place on land which can be cultivated as rotational, or temporary grass. On such land livestock are competing with food crops. Use of this land offers opportunities to intensify animal production through use of more productive grass mix species and varieties, which are then grazed by livestock breeds developed and managed to best utilise such forage. These more intensive grazing systems whether for milk, beef or sheep may still be predominantly grassland farms, or they can be part of wider grass and crop rotations on mixed livestock arable farms. There is a wide spectrum of combinations of grazing livestock and cropping found in the EU. The grassland in such systems contributes in many ways: improving soil structures, and fertility, weed and pest control, plus of

46 Although even in all-grass systems there is often some winter supplementary feeding for cattle and sheep and many calves from all-grass suckler cows are finished in more intensive systems.

47 The concept of high nature value farmland refers to the causality between certain types of farming activity and corresponding environmental outcomes, including high levels of biodiversity and the presence of environmentally valuable habitats and species (Eurostat, Agri-environmental indicator)

48 http://www.biodehesa.es/

course the benefit of the 'golden hoof' of the nutrients spread by the grazing animals.

To this point, the argument is that a certain farmed ruminant livestock population can be justified as a way of utilising for food production a considerable area of often marginal land which supports natural and semi-natural grassland. This would not, of course, include the more fertile land suitable for food production. The food output of such areas would be lower if not farmed and left to generate scrubland and eventually woodland (which could include agro-forestry) or if managed as natural grasslands for wild populations for example of deer. The second dimension of the pasture utilisation case for livestock is that this enables mixed crop and livestock farming systems which have cropland: grassland rotations, or at least animals and croplands in close proximity offering agronomic benefits of weed and disease control, and ecological benefits[49]. The main self-styled "sustainable" farming systems, organic, biological and ecological agriculture generally emphasise the desirability of integrated, mixed crop and livestock systems as one of the building blocks.

In addition to using pasture, livestock also make significant use of crop by-products and residues. The feed industry creates value from a variety of by-products from the food & drink and biofuel industry by enabling these products to be fed to livestock. The EU feed manufactures association FEFAC estimate that these materials represent 11% of its inputs for compound feed. It is increasingly argued that new processing techniques could restore traditional feeding of pigs, and even poultry, with food waste material[50], a practice which was halted by concerns following the outbreak of Bovine Spongiform Encephalopathy (BSE) in the UK in 1996 (Packer, 2006).

2.2.3. Contribution to livelihoods and culture

Before settled agriculture, mankind lived as hunter - gatherers where a high proportion of energy intake is often characterised as coming from hunted animals[51]. Human metabolism was adapted for fat burning and storing, people were adapted to sporadic feasting followed by periods managing on lower intake. A higher cereal and root vegetable contribution to energy came later with settlement, the domestication of animals and development of crop production. This in turn was helped by recycled nutrients from animal manure and night soil.

Livestock farming has shaped the physical and social landscapes of the EU. There are many parts of Europe where the only type of farming is pastoral farming, and where livestock represent a store of wealth for farming families, especially for tenant farmers. Extensive livestock contribute to the preservation of habitats of community interest in HNV areas, many of which overlap with Natura 2000 network areas (Keenleyside et al., 2014). Livestock also play an important role in fire prone areas, clearing fuel from the understory[52].

Livestock contribute an important part of the agricultural and food economy. Livestock, meat and animal products account for 43% of the value of the EU28's agricultural output. The EU's Animal Task Force cites the contribution as "€130 billion annually, 48% of the total agricultural activity and creating employment for almost 30 million people" (Animal Task Force, 2016). The largest components of the animal output are milk (~33%), pigmeat (22%) and cattle (18%). The share of animal output in total agricultural output is more important in some MS than in others. It is highest at 75% in Ireland (cattle and dairy), 64% in Denmark (pigs), 62% in Finland (dairy) and 60% in the UK (cattle, dairy and poultry). Livestock accounts for similar shares of agricultural employment. Modern production agriculture contributes a relatively small part of the total value and employment in the food chain which extends from the upstream input suppliers (seeds/genetics, feeds, animal health products, machinery, fertiliser and service providers) to the downstream processing and distribution industries (abattoirs, transport, processing, food manufacture, wholesaling and distribution) and increasingly the food service sector - canteens, restaurants, fast food outlets, snacks and sandwich outlets, and strong sector of print and broadcast media. A significant part of EU 'manufacturing' industry is in food processing and food service and the proportion which is livestock product associated is likely to be a comparable proportion as livestock are in agricultural value added. Indeed, it may be higher given the added difficulties and costs of the perishable and hygiene-sensitivity of animal products if not correctly handled (most food poisoning is animal product related).

Livestock heavily influence the aspects of land use and the rural economy which develop around tourism and recreation. Walking, hiking, camping, riding, cycling and sometimes skiing predominantly favour the areas dominated by ruminant livestock. A critical aspect of

49 Mixed farming can confer these benefits, but there are opportunity costs if inherently inefficient animals convert grains and other crops which could directly have fed humans. This fundamental truth is also reflected in the generally observation that mixed farming is less rewarding financially than specialised crop and animal production. (See Eurosat FADN data on farming income by farm type).

50 There is a fuzzy line between by-products, residues and wastes. The EU's waste strategy, prioritises the prevention of waste rather than seeking to justify it by putting it to good use. The circular economy strategy seeks to extract the highest value from material flows, for example by cascading use. The complexity of the current flows of these materials, and how they could change if European diets adapted to the concerns in this report deserve detailed study.

51 Solid evidence on this is hard to find: these people may well also have consumed much fish, molluscs, insects and also plant materials.

52 http://ec.europa.eu/environment/nature/rbaps/fiche/rapca-red-de-areas-pasto-cortafuegos-de-andalucia-_en.htm

the public enjoyment of such areas is the open landscape managed by grazing livestock which provides the views of the topography. In addition, the associated field boundaries, hedges, banks and walls, and the traditional buildings, barns and byers/stables form part of the cultural landscape which attracts visitors. Without livestock the natural vegetation would quickly develop to scrub and eventually forest which closes down the views.

Pointing out that a sector is a significant generator of economic activity and employment is not a sufficient justification for the unchanged continuation and growth of the activity. If it is concluded that this activity is associated with unacceptable harm to human health or the environment, and is fundamentally unsustainable, then adaptation must, sooner or later, be contemplated. Knowing the economic importance of the sector does however indicate the scale of political, economic and social challenge, and the adjustment assistance which may be required, if it is concluded that it has significantly over-expanded and is seriously out of balance necessitating more than marginal adjustment.

2.2.4. Climate harm: GHG emissions

The contribution of livestock to climate change is the most significant negative impact of this activity globally and provides the strongest argument that concerted action may be required to limit current consumption in some regions and to limit consumption growth in others. Dealing with the climate impact of livestock motivates much of the current research on livestock feeding, breeding and manure management. The livestock sector will also have to adapt to the changing climate. Impacts are expected to be particularly felt on animal productivity, animal health, the availability of feed and water, and the productivity of pastures (FAO, 2016).

The total global contribution of the livestock industry to global GHG emissions (in CO_2 equivalent) is estimated to fall somewhere between 9.4- 14.5% (FAO, 2016; IPCC, 2007; Winkler and Winiwarter, 2015). This value, includes direct emissions from animals (i.e. enteric fermentation and manure) as well as emissions linked to the production of feed. This contribution is the same as the direct contribution of all global transport, also 14%[53]. Whilst abatement costs in some agricultural systems are high, it is suggested that there is scope for significant reductions in emissions from livestock – principally because productivity of livestock production is so low in many countries[54]. The FAO estimates that global methane emissions could be cut by 41% if known improved animal feeding and health practices were adopted (FAO, 2016).

In the EU27, livestock are responsible for 51% of all methane emission and 78% of all the N_2O emitted by the agricultural sector, including emissions from feed produced only on EU soil. Based on standard IPCC methodology, the European Environment Agency (EEA) reports that the EU27 agricultural sector is responsible for 9.8% of total EU GHG emissions (for comparison, the EU transport sector's share is 25.8%[55]). Of this total, 4.7% comes directly from livestock (manure management and enteric fermentation) and 5% from crop production from agricultural soils, part for animal feed and the rest for human food production. Some authors use Life Cycle Analysis (LCA) to point out that as the EU imports a considerable volume of animal feed, then the emissions associated with the production of this feed should be ascribed to the EU. Accordingly, Leip et al. (2015), calculate that 39% of the emissions from the production of agricultural products in the EU occur outside the EU territory through feed imports, feed transport and emissions from land use change in other countries. Based on their estimates it is calculated that livestock production is the source for 81-86% of all EU agricultural emissions (within and outside the EU territory) and that the production of feed accounts for half of these (Leip et al., 2015; Lesschen et al., 2011). In IPCC national accounting, which underpins international agreements on climate, all emissions are counted at source i.e. the territory on which they arise. Thus, for the EU to count emissions associated with Brazilian soya would result in double counting. However, as an educative tool for policy makers and citizens to understand the impact of the EU's consumption decisions there is sound rationale for the Life Cycle Approach which incorporates all domestic and overseas emissions.

Figure 5 summarises the livestock emissions calculated for the EU27 by species by Lesschen et al. (2011). The figures are measured in carbon dioxide equivalents CO_2e[56], emissions from land use change, transport and packaging are not included.

Even though there are many more (1.7 times more) pigs in the EU than cattle, their emissions are considerably lower, mainly coming from the manure produced and due to N_2O emissions from soils (direct and indirect) released

53 There are other larger estimates of the contribution of livestock ranging as high as 51% based on different Global Warming Potenial coefficients and calculated by supposing that land used for livestock feed production could be diverted to biofuel production (Goodland and Anhang, 2009).

54 Although efficiency gains which reduce GHG emission per unit of product may come at a cost in impacts on other aspects of the environment and animal welfare. These interactions are considered in the later chapters.

55 European Commission, https://ec.europa.eu/clima/policies/transport_en

56 Carbon dioxide equivalents is the accepted way of summing the emissions of the three main greenhouse gases, CO_2, CH_4 and N_2O by multiplying the volumes of CH_4, and N_2O by their global warming coefficients.

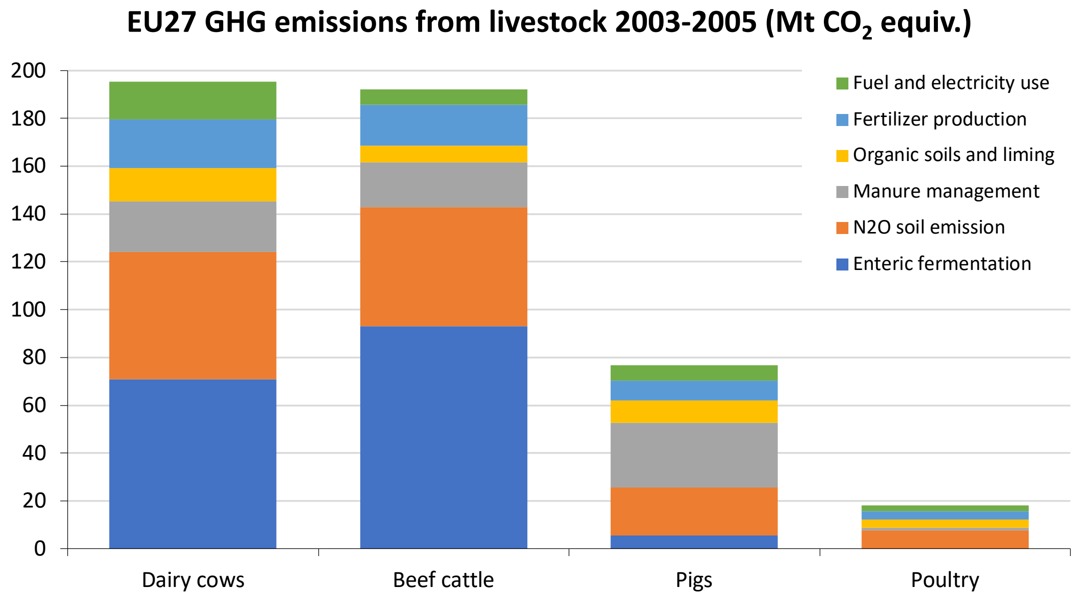

Figure 5. **Total GHG emissions from livestock in the EU27 for the period 2003-2005 using the MITERRA-Europe model** (adapted from Lesschen et al., 2011)

from feed production. These data clearly show that the principal sector to target for climate change mitigation is ruminants, especially cattle and including both beef and dairy cows[57]. Emissions per kg of meat differ greatly between the species. Ruminants have the largest emissions with commonly reported values of 20-30 kg CO_{2e} per kg of beef and 9-28 kg CO_{2e} per kg of sheep and goat meat. Pigmeat has lower emissions, 5-10 kg CO_{2e} per kg of meat, and poultry the lowest figures, 5-7 kg CO_{2e} per kg (Leip et al., 2010; Weiss and Leip, 2012; Winkler and Winiwarter, 2015). These ranges for each species are wide, and even larger variations can be found in specific production systems in different countries: 14.2 kg CO_{2e}/kg beef in Austria compared to 44.1 CO_{2e}/kg beef in Cyprus. Such differences can be explained in the quite different performance levels of production in different systems (McAuliffe et al., 2018) and in the length of the grass growing season. Emission rates per kg of dairy products are also complicated by the inclusion (or not) of the beef and veal which are co-products from the dairy herd. However, the general conclusion is that systems which are most productive, as measured in the conventional sense of faster live weight gain, higher feed conversion efficiency, highest milkyields per cow, or eggs per bird will have the lower emissions per unit of product. These differences in emissions according to production efficiency provide the evidence that total emissions could be greatly reduced if efficiency were levelled up to the best performers. However, this in turn illustrates the complexity of the challenge because greater production intensity may be associated with deterioration of other environmental indicators, e.g. nutrient leakage, and may be accompanied by animal welfare concerns. Adding the public goods, e.g. cultural ecosystem services associated with livestock and their pastures, further complicates the assessment of these seemingly clear indicators.

Greenhouse gas accounting and measurement methods are still evolving, and there is no doubt that the fluxes of GHG are more complex in agriculture and land use than in other sectors. It is often claimed that livestock grazing systems offer a beneficial climate contribution through C capture. The argument is that ruminants feeding solely on grass can only emit as much carbon as they obtain from the grass itself. And since the grass captures atmospheric carbon to grow, ideally this would be a system in equilibrium. However, carbon sequestration rates by pastures are highly site specific and depend on numerous factors (type of plants, grazing intensity, climate, fertilization, fungal and bacteria dominance). In general, there is scope for grasslands to be managed more effectively to increase C capture, but it is neither simple nor easily verified. Despite a large interest in finding a generalized value for C sequestration to include in budgets we are very far from achieving this. In its estimates, the IPCC assumes that after 20 years grasslands stop accumulating carbon (Smith, 2014). Therefore, soils eventually become saturated in

57 There is much greater variability on emissions for cattle, depending on the farm system than for monogastrics, thus further analysis must disaggregate by system: breed, feed, duration, purpose.

soil organic matter while the cattle and sheep continue to respire CO_2 and, of course, they emit methane with its global warming potential some 25 times higher[58]. Garnett et al. (2017) review many studies and conclude that grazing does not offer a significant C sequestration mitigation option. Only in very limited and specific systems can it lead to small amounts of C sequestration. Since emissions usually outweigh sequestration, they conclude that grazing livestock should be considered net contributors to GHG emissions. Other complicating factors are that grazing livestock take a longer time to reach finished weight compared to faster growing grain fed animals, and the manure emissions of grazing animals compared to housed cattle[59]. However, this does not exclude the fact that better grassland management can deliver many other benefits including reduction in soil loss, enhanced water quality and storage, biodiversity, soil health and contribute to animal health and welfare (Garnett et al., 2017).

2.2.5. Nutrient cycling

Livestock have played a traditional role in cycling nutrients. For millennia, livestock manure has contributed to maintaining soil fertility in mixed crop-livestock farming systems by adding organic matter and nutrients. The combination of spreading manure collected from animals housed during winter months, incorporating crop residues and composted vegetable material, and rotating temporary pastures with other fodder, particularly legumes, and arable crop have been the traditional ways of building and maintaining soil fertility. Over the years, the sheer expansion, increasing scale and concentration of production of both crops and animals has led to specialisation and separation of crop and animal production. More efficient breeding and harvesting have meant that a declining portion of the crop plants is returned to soil after harvest, and there is now little or no grazing by animals in many arable areas. These technical and structural developments were enabled and encouraged by the development of manufactured fertilisers and convenient means to spread them. Crop nutrients in such systems are provided by adding nutrients to the soil in the form of mineral fertilisers, transported organic manures and increasingly the digestate from nutrient recovery processes like anaerobic digestion.

58 Global warming potentials compared to carbon dioxide vary depending on the period over which they are calculated, the cited figure is for 100 years, IPCC 2007 https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

59 In addition to these arguments which cast doubt that grazing livestock often lead to net carbon sequestration is the usually overlooked argument of the counterfactual to livestock grazing. Without man's deployment of the land for livestock grazing the natural vegetation of most extensive grazing areas would otherwise have been woodland, peat or wetland. Their 'improvement' for grazing will have been associated with many years of C emissions.

It is important to understand and acknowledge that livestock do not supply nutrients such as nitrogen to agriculture. Nitrogen is supplied to agriculture in only three ways: by biological nitrogen fixation in the root nodules of legumes, by lightning, and industrially in the Haber Bosch process used to manufacture mineral fertiliser.

Animals cannot and do not add N to the system they rather inefficiently cycle it. The quantity of nutrient cycling through animal manure is large, it is estimated currently to provide 34% of the total nitrogen input and 53% of the phosphorus input used by EU agriculture (Buckwell and Nadeu, 2016). EU livestock excrete around 1400 Mt of liquid and solid manure annually (Foged et al., 2011). Of this 600 Mt is in the form of liquid pig and cattle manure and 300 Mt as solid cattle manure, and the remainder is produced by other livestock groups or deposited directly on land by grazing animals (de Vries et al., 2015). The concentration of nutrients and organic matter in manure varies by manure type (liquid vs. solid) and animal type. Poultry manure has the highest nutrient concentration among all manure types. However, over the course of a year, a chicken will excrete less than 1 kg of N while a pig excretes between ten and twenty times this amount (Velthof et al., 2015). In total, two thirds of the annual excreted nitrogen in the EU in the form of manure derives from cattle (Velthof et al., 2010). In addition to cycling macro-nutrients (N and P) back to the soil, solid animal manure, when well-rotted with straw or other biomass, contributes large amounts of organic carbon and soil organisms. This increases soil fertility by building the carbon stock in the soil, it improves soil structure, increasing microbial biomass and enhancing water and nutrient retention in soils. However, the specialisation and geographical concentration of some livestock production, and changes in housing and bedding of cattle (and horses), has diminished these benefits. And since the majority (>90%) of manure enters the field unprocessed it does not always provide the nutrient composition best suited to the plants. Consequently, large quantities of nutrients are lost annually from the fields polluting the air and watercourses.

Problems of cycling nutrients via animals have increased with the expansion and spatial separation of the livestock sector in certain EU regions, leading to gross regional nutrient imbalances. The most critical are nitrogen (N) and phosphorus (P) surpluses[60]. Two processes are at work simultaneously. Animal production is being geographically concentrated and nutrients are being imported into

60 These are calculated as the difference between these nutrients supplied to land as mineral and organic fertilisers (manure) and the calculated off-take in the form of crop and animal products, and purchased and sold feed and livestock.

these regions as mineral fertiliser and as feed[61]. Livestock farmers try to circulate as much of the resulting manure onto the croplands in the region as they can but the density of animals is such that the absorption capacity is exceeded. The result is considerable leakage into water and atmosphere.

Accounting these nutrient flows has been accomplished by large EU-wide projects, for nitrogen (Sutton et al., 2011) and for phosphorus (van Dijk et al., 2016). The scope to intervene and recover and utilise more of the flows was the subject of the RISE Foundation report on Nutrient Recovery and Reuse (Buckwell and Nadeu, 2016). Figures from these three studies indicate that the annual total N input to the EU livestock sector is around 9 Mt in the form of fodder, grass and compound feed. Yet, only 18% of this nitrogen reaches the consumer in the form of livestock products. Similar estimates have been made for phosphorus (P) flows through the food system. In this case the percentage of P input that ends up in livestock products is higher at around 30%.

The fate of the remaining N and P is complex. In the first instance, most of these elements ingested by animals is excreted as faeces and urine; farmers try to recirculate as much as possible of these back to agricultural soils. However, depending on the manure collection and distribution systems much, especially N, volatilises and finds its way to the atmosphere as ammonia or nitrogen oxides. Another component is leached through soils into water courses and eventually into lakes, seas and oceans (both N and P). These nutrient emissions pose severe environmental challenges. Livestock systems account for a very large share of losses of nutrients in the EU. They are responsible for 81% of the nitrogen input to the aquatic system from agriculture (Westhoek et al., 2015). In addition, the livestock sector is responsible for 23-47% of all N river load to coastal waters and 17-26% of P loads to rivers (Leip et al., 2015). These leakages to water result in large eutrophication problems. Eutrophication is the process whereby high nutrient loadings in water leads to the growth of algae. When these algae die, they decompose on the bottom of the rivers, lakes and oceans consuming large amounts of oxygen. This leaves the water in a state of a very low oxygen concentration and aquatic species that depend on oxygen migrate or die, reducing biodiversity and ecosystem services such as water provision and purification. Recreation and tourism are also affected.

Air quality is also affected by excessive nutrient loads. The main gases contributing to air pollution from the livestock sector and associated feed production are mainly in the form of ammonia (NH_3), but also as nitrogen oxides (NO_x), nitrous oxide (N_2O) and particulate matter (especially from poultry farms). 87% of the NH_3 emissions into the atmosphere arise from agricultural production (Westhoek et al., 2015). Not all farms contribute equally, the largest 5% of livestock farms are responsible for 80% of agriculture's ammonia emissions[62]. Despite some progress in the last decades, ammonia emissions remain a very important issue to be solved in the EU[63]. The effect of these emissions is both direct, from the animals and their manure, and indirect from their share (approximately 40%) of crop emissions e.g. of nitrogen oxides (NOx) associated with fertiliser use. Another kind of air pollution is odour from intensively housed animals. Air pollution has received less attention than it merits in agricultural debates. Yet it is considered the largest environmental health risk in the EU and it is estimated that one in four Europeans will die or fall sick due to air pollution during their lifetime (WHO Regional Office for Europe and OECD, 2015). Societal costs are estimated to be very high, roughly between €330 and €940 billion a year (data for 2010) (EEA, 2015).

In short, this nutrient cycle is long, inefficient and leaky and farm animals, especially ruminants, lengthen it and render it more inefficient and leaky.

These developments are now well documented across Europe. Problems of nutrient surplus are especially serious in the main dairy, pig and poultry producing regions of France, Belgium, the Netherlands, Denmark, Germany, Italy and Spain. In such regions, manure becomes perceived as a waste to be disposed of, rather than a valuable resource. The high levels of nitrogen in groundwater and surface waters in these predominantly livestock regions show that manure management and its utilization has become strongly out of balance over several decades. Important legislation, specifically the Nitrates Directive (1991) and subsequently the Water Framework Directive (2000) have been introduced to deal with this issue. But it is taking a long time for these to show results. The Nitrate Directive deals only with organic nitrogen loads at farm level, not nitrate surplus. The Water Framework Directive operates at river basin level aims to get all water into good ecological and chemical status. Although the situation is improving, more than half of the EU territory still exceeds what are considered critical nitrogen loads (Figure 6).

In conclusion, air and water pollution are the second largest negative impacts of livestock in EU's environment after climate change. The EEA estimates that none of

61 Whilst the source of the N for mineral fertiliser is from the atmosphere, or nowadays mostly from natural gas, its manufacture in the Haber Bosch process is an extremely high energy consuming activity, much of which is fossil fuel. Phosphorus is a mined mineral, and is also quite fuel (and water) intensive in its manufacture.

62 Facts and figures on agriculture reductions as proposed under the Commission's NECD proposal

63 Commissioner Vella recently mentioned this: https://www.euractiv.com/section/agriculture-food/news/vella-ammonia-emissions-is-an-enormous-problem-that-needs-to-be-tackled/

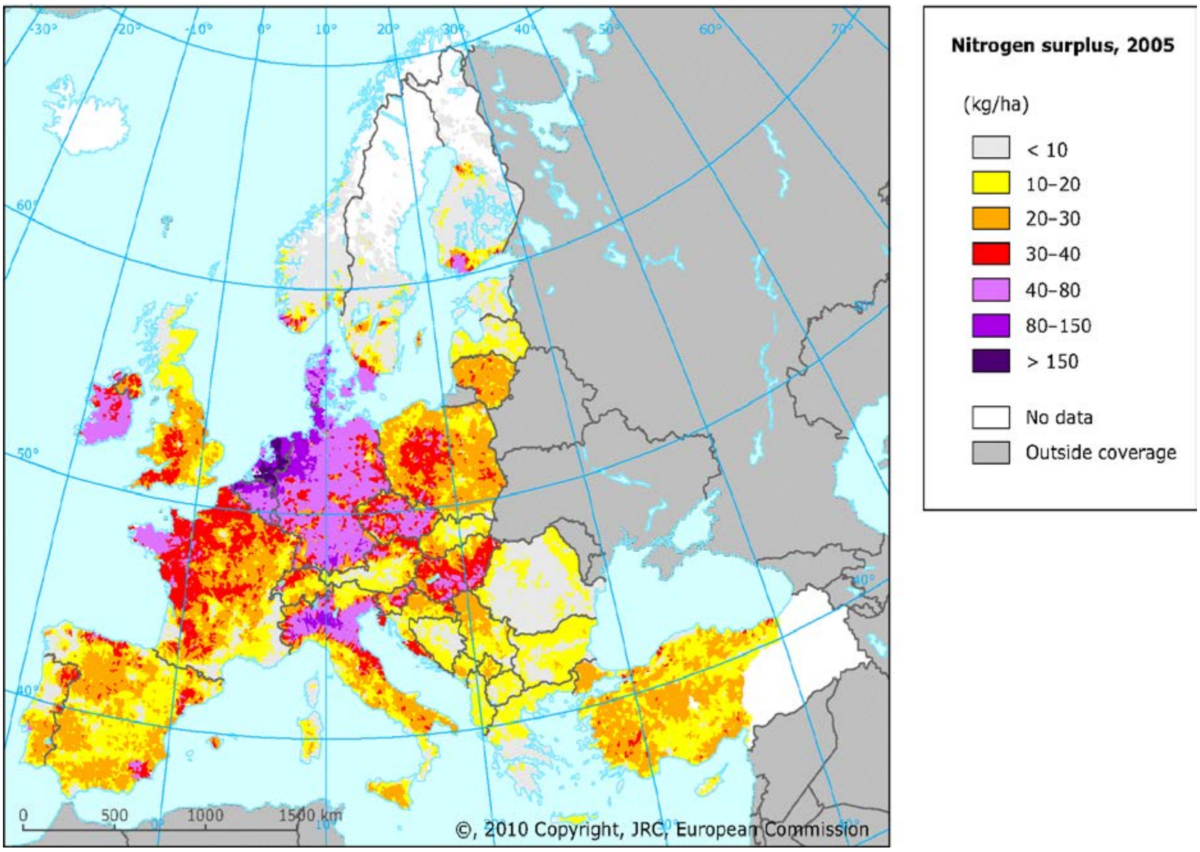

Figure 6. Nitrogen surplus in kg per hectare of agricultural land in the EU27 in 2005 (Source: EEA, 2010)

the 2020 targets related to the reduction of the impact of excess nutrients in the environment will be met[64] In particular, these targets seek to (i) manage the nutrient cycle in a more sustainable way (7th EAP), (ii) reduce areas of critical load exceedance with respect to eutrophication by 43 % from 2000 levels (Air Pollution Thematic Strategy), (iii) achieve good status of transitional and coastal waters and freshwaters (Water Framework Directive) and (iv) reduce the overall impact of production and consumption of meat, dairy, fish and seafood in the food sector (7th EAP). The United Nations (2011) have also emphasized that '*livestock production is probably the largest sector-specific source of water pollution*'.

2.2.6. Biodiversity

The direct and indirect (via feed production) impacts of livestock on biodiversity, and on the ecosystem services it provides is not as well quantified as greenhouse gases and nutrient flows. The biodiversity effect is also complicated by the fact that whilst the negative impacts dominate in many situations, some livestock systems provide valued positive impacts. Much depends on the livestock and feed crop systems especially their intensity measured in inputs or outputs per hectare. The main direct negative impacts occur as permanent pastures are intensified reducing species diversity, or are ploughed up and replaced with more intensively managed grass and other herbage, and through technology developments such as the switch from haymaking to silage as the main form of herbage conservation. The biggest indirect negative effects are through the destruction of natural or semi-natural habitat as is cleared, or drastically simplified, for crop production. Global estimates indicate that food production accounts globally for 60-70% of total biodiversity loss (Kok et al., 2014) of which the livestock sector is held responsible for 30% of biodiversity losses (Westhoek et al., 2011). Agriculture has been identified as the most frequently reported pressure and threat to wildlife loss and habitat degradation in Europe (European Commission, 2015). For Europe, livestock are estimated to be responsible for 78% of the negative impact of agriculture on EU biodiversity when including the production of feed (Leip et al., 2015).

Impacts on biodiversity take place through the way land is managed and used to produce crops for animal feed or managed as grassland. These activities may lead to the

64 Source: Thematic priority objectives from the 2016 EEA Environmental Indicator Report in which livestock play an important role and expected accomplishment of targets, https://www.eea.europa.eu/airs/2016

creation or destruction of habitat for certain species. Well managed grassland ecosystems, and more heterogeneous mixed farms can contribute to increase biodiversity, although conflicts can arise between managing grasslands for production versus conservation (Plantureux et al., 2005). Most so-called high nature value farming systems are associated with extensive grazing livestock (Keenleyside et al., 2014). Many studies focusing on grazing systems recognise that these ecosystems contribute to maintain and manage biodiversity, although the links between richness of species and pasture and herd management are complex and not always clear (Bernués, 2017). Extensive livestock systems practiced over decades allows the co-development of groups of plant and animal species around them. These systems are invariably found in the remoter, often upland and mountain areas of MS. The farming systems are often associated with local breeds, more traditional farming systems, and local produce, with animals housed in traditional buildings.

As land management is intensified by improving pasture, this generally means a combination of: re-seeding with more productive, but less diverse, grass mixtures, adding fertiliser, increasing grazing intensity resulting in more animals per hectare, and substituting (earlier season) silage for (later) haymaking. The result of such management changes is that the conservation of many species becomes at risk. There are many documented examples of this process throughout the EU such as the negative changes in bird populations documented in Mediterranean areas where upland pastoral systems have disappeared in favour of more intensive livestock systems (Fonderflick et al., 2010). In general, managing grasslands to maximise production is in conflict with a management to maximise biodiversity (Louwagie et al., 2009).

The negative effects come about both through the homogenisation and simplification of farming systems (Benton et al., 2003) and through the practices deployed in those systems. Intensification invariably means increased reactive nitrogen in the environment, through deposition and leaching, and this is a leading driver of global biodiversity loss (Sala, 2000). The many reactive nitrogen hotspots in the EU are indicated in the section above (Sutton et al., 2011). In agriculture, reactive nitrogen is introduced into the environment through manure management and the use of artificial fertilisers. The higher concentration of nitrogen encourages certain species which respond fastest and furthest to the high nutrient status to the detriment of another species. The result is that plant biodiversity systematically falls and this reduces feed sources (pollen, seeds) and, nesting places and shelter for invertebrates and other species which in turn reduces feed sources for vertebrates small and large. How far this sequence goes depends on multiple factors. Biodiversity losses can also occur as the routine use of herbicides leads over time to loss of plant species in fields and around fields, and consequently there are fewer seeds for birds and other species. Systematic use of insecticides over time has inadvertently reduced beneficial insects as well as targeted crop pests, and collateral damage is caused to pollinators, and to insects and their grubs on which other species feed, such as birds (Eichberg et al., 2016).

Biodiversity is a multifaceted concept. Two prime indicators which are in widespread use because they involve charismatic species which the public love and on which therefore there is a wealth of data (and people willing to collect data) are the farm land bird index and the butterfly index. These are of deep concern in themselves but they reveal a great deal about the food chain on which these species live. At the EU level, Eurostat uses the Common Bird Index[65]. The encroachment of pastures reduces plant and insect diversity (Koch et al., 2015) and causes a decline in species with unfavourable conservation status in the EU. In grasslands, alternating between mowing and grazing has been suggested to contribute to the development of both grasses and other typical grassland species and herbs, enhancing biodiversity (Mládková et al., 2015).

It has been argued that reduced meat consumption could contribute to halt biodiversity loss (Machovina et al., 2015). The European Commission itself has recognised that livestock may be a leading player in the reduction of biodiversity through its demand on land ('European Commission staff working paper 2011'), but did not include objectives and measures for livestock in the Biodiversity Strategy to 2020[66]. On a global scale, the expansion of cropland and grasslands at the expense of natural habitat such as forest is indeed one of the key factors of biodiversity loss and the areas in which livestock is more likely to expand in the coming years, namely the tropics, are biodiversity hotspots.

Viewed globally, the expansion of farmed livestock numbers has led to an over-representation of a very limited number of species, reducing biodiversity on earth. Currently, of the 40-species domesticated by human cultures only 14 account for 90% of the total livestock production (Biodiversity in Development, 2010). But the most important biodiversity effect is through the resources needed to support the grazing livestock directly and the crops fed to livestock. The resulting impacts on the environment has placed enormous pressure on other species reducing biodiversity on the planet. Although this report focuses on terrestrial farmed animals and not on wild or captive fisheries, it should be noted that livestock production has increased the pressure on global fish resources. This is

65 Although this indicator has a narrow focus compared to the EU policy objectives on biodiversity and ecosystem services, it is considered to be the best available dataset and also to be indicative of general environmental status
66 (SEC(2011) 540 final)

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because one third of global fish captured, mostly in the form of 'forage fish', go into animal feed in the form of fish meal and fish oil (Alder et al., 2008).

2.2.7. Land use and soil degradation

Almost two-thirds of the EU´s agricultural land is used by livestock productions systems (Leip et al., 2015). In addition to land use, pressure created from the growing consumption of livestock is also responsible for land degradation in many parts of the world through the production of feed, sometimes involving land use changes. Although feeding grain to livestock started as a way to valorise surpluses, the amount of land explicitly devoted to grow feed has increased rapidly. The FAO estimates that 60% of the global production of maize and barley between 1961 and 2001 was used to feed livestock (Steinfeld et al., 2006) This has resulted in reduced soil quality and increased erosion due to tillage operations, use of manufactured fertilisers and of crop protection products. In the US, it is estimated that livestock are responsible for 55% of all erosion and sediment produced when the effects of both pasture management and feed production in croplands are fully accounted for (Steinfeld et al., 2006). Whilst adequate grazing density can contribute to maintaining soil quality, even modest overgrazing can have serious negative impacts as seen in some areas in the UK and in some Mediterranean regions. There is little doubt that the introduction of headage payments under Europe's Common Agricultural Policy for sheep in the late 1990s led to systematic over-grazing with recorded negative impacts on soil erosion, nutrient overload, reduced water infiltration and poorer flood protection. The subsequent removal of these coupled payments saw a corresponding drop in sheep numbers. Identifying what might be considered as a socially desirable intensity of grazing is partly a matter of social taste. Some, e.g. Monbiot (2013), favour 're-wilding' of upland areas and would prefer there to be fewer or in places no sheep at all. Others laud the open farmed cultural landscapes as providing iconic setting for hiking and camping as witnessed by the extensive purchase and management of such areas by conservation organisations such as the UK National Trust[67] and the encouragement of hiking following the ancient pathways of transhumance seen in the Pyrenees. In the Mediterranean basin, there are several areas where overgrazing has

67 The National Trust, founded in 1995, is the UK's largest member organisation with over 3 million members. It owns and manages (mostly through small tenanted farms) 248,000 hectares including a significant share of Britain's most loved upland and coastal landscapes.

been evident leading to serious soil erosion. The problem has been intensified in conjunction with increased frequency of forest and scrubland fires and those on steep slopes (Lasanta, 2010).

2.2.8 Antimicrobial resistance (AMR) and zoonoses

The large increase in meat production experienced since the 1960s was considerably helped by the discovery and use of antibiotics. Since the 1950s, antibiotic drug use in animals has traditionally responded to three objectives: curing diseases, preventing diseases and promoting growth. The EU banned hormone-based growth promotors in 2006 but in many parts of the world it is still permitted (the US recently banned its practice in early 2017). The use of antibiotics has assisted the growth and intensification of the livestock industry while keeping bacterial infections under control. But this necessitated a strong increase in quantities used, so that livestock farms became the largest consumers of antibiotics worldwide. In the EU, between 2011 and 2012, the use of antibiotics on farm animals was double that used in human medicine (ECDC et al., 2015). More than half of the use is prophylactic and not in response to a specific disease diagnosis but given to healthy animals to provide a preventive effect. The extent of this practice differed among MS[68]. For instance, in the Belgian pig industry, 93% of the treatments were considered preventative in 2012 (Callens et al., 2012). In the US, where livestock account for 70% of total antimicrobial consumption, 80% of the antimicrobials given to animals are used for non-therapeutic treatments (i.e. on healthy animals)[69]. These practices were of course supported by the generally accepted dictum that prevention is better than cure, but plainly they did not take sufficient account of the dangers both to farm and human use of antibiotics from the development of resistance.

Antibiotic use has thus assisted the intensification of production of mainly pigs and poultry (VMD, 2015)[70] but this has come with a large cost. The development of **antimicrobial resistance** (AMR) will have commenced as soon as the first antibiotics were used on humans and farm animals, but has now increased to become a global threat that will require unprecedented international cooperation. AMR defines the ability of certain microorganisms to resist antimicrobial (including antibiotic) treatments. Once they become resistant to most antimicrobials, organisms are generally referred to as 'superbugs'. AMR has been defined as one of the most important global economic and societal challenges facing mankind and is projected to be the cause of death of 10 million people annually by 2050 globally (ECDC, 2009). Currently, it is estimated that antimicrobial resistance results in the annual death of 25,000 people across the EU – 700,000 people globally – and in losses of up to €1.5 billion[71]. AMR currently affects some bacteria involved in widespread diseases such as pneumonia, bloodstream infections, urinary tract infections or gonorrhoea. Besides direct impact on disease treatment, AMR can also cause severe complications in surgery and cancer chemotherapy treatments[72]. However, to get a correct perspective it is worth noting that the European Medicine Agency's Committee for Medicinal Products for Veterinary use (CVMP) said in the strategy on antimicrobials 2016-2020 that "*it is recognised that the biggest driver of AMR in people is the use of antimicrobials in humans or human health*" (EMA, 2016).

It is generally agreed that the excessive, and especially preventative, use of antibiotics on farm animals has been a major factor in bringing about AMR, although part of the resistance arises also from human use (Review on Antimicrobial Resistance, 2015)[73]. The risks for public health are complex to assess. 90% of antibiotics given to EU livestock are administered to animals orally (EMA, 2017), so these are usually absorbed via the intestine and transformed within the organism of the animal and surveillance documents that animal produce is free of harmful residues. However, part of the antibiotics inevitably end up in animal manure and the percentages ranges between 17% and 90% of the administered antibiotics globally (Massé et al., 2014). The acknowledgement that AMR poses a real threat to human and animal health and that coordinated global interventions are needed has only recently been made at a high political level. Globally, the WHO did not publish its first report on the topic until 2014, although in 1997 it had warned against their use for 'growth promotion' if they increased the resistance of antimicrobials used in humans. The impact of AMR on human health has three main components: antibiotic-resistant food-borne infections, spread of resistant genes and new multi-strains of bacteria that have in the past not been food related (Compassion in Animal Farming, 2011).

The EU has been a forerunner in the identification and combat of AMR. In 2001, the European Commission presented a 'Community Strategy against Antimicrobial Resistance' in which actions were identified in four key areas (surveillance, prevention, research and product development, and international cooperation) to contain and fight against AMR. The 2006 ban on antibiotic use for

68 There is wide variation also in the comparative rates of use of antibiotics as between farm animals and humans across countries too, see the 2017 2nd EU report of the Joint Interagency Antimicrobial Consumption and Resistance Analysis (JIACRA).
69 See http://www.arc2020.eu/80-per-cent-of-all-antibiotics-sold-in-the-us-are-given-to-perfectly-healthy-animals/
70 In the UK, 90% of farm antibiotics are used in intensively farmed pigs and poultry
71 See:http://www.ema.europa.eu/ema/index.jsp?curl=pages/special_topics/general/general_content_000439.jsp
72 According to the Lanced Infectious Diseases Commission
73 According to this study, 72% of papers by academics found evidence of a link between the farm use of antibiotics and resistance in human medicine.

growth promotion was a step forward, but a decade after the ban it has become apparent that farmers claimed an increased therapeutic need, resulting in little change in antibiotic use levels. A directive to ban preventative antibiotic use on farms is now in process in the ordinary legislative process of the EU. Much is at risk from AMR since many of the antibiotics used in animals are also used in humans and global consumption of antibiotics is still predicted to increase by 67% between 2010 and 2030 (Van Boeckel et al., 2015). Recent data from the EMA shows that between 2011 and 2015 sales of antibiotics for use in animals in Europe fell by 13.4% (EMA, 2017), although this average hides the fact that their use continues to grow in some EU countries and more action is needed.

Zoonoses are diseases or infections that can be transmitted directly or indirectly through animals and humans (EFSA). The transmission can take place through direct or indirect contact with the affected species, through contaminated foodstuffs or through a vector carrying the pathogen (i.e. bitten by a tick). The emergence and amplification of zoonoses has been linked to modern farming practices and agricultural intensification, and is further exacerbated by environmental changes (Jones et al., 2013). Over the last 10 years, 75% of emerging infectious diseases that have affected humans originated from animals or animal products (EFSA and ECDC, 2017). Zoonosis is therefore a major public health problem, but its impact on the livestock sector is also significant, representing losses and barriers to trade.

Notification of most of the diseases is mandatory for MS under the Zoonoses Directive (2003/99/EC). The European Centre for Disease Prevention and Control (ECDC) publishes annually a report on the trends and sources of zoonosis and foodborne diseases. The most commonly reported zoonosis between 2012 and 2016 (EFSA and ECDC, 2017) has been gastrointestinal disease caused by campylobacteriosis, with over 200,000 confirmed cases per year, although up to 9 million cases are estimated to occur with total annual costs of 2.4 billion euros (EFSA, 2011). It is also considered to be the most common cause of gastroenteritis globally (WHO, 2013). Gastro intestinal disease caused by salmonellosis ranks second in the ECDC reports, with over 90,000 confirmed cases per year in the EU. The most important food vehicles in such outbreaks are eggs and egg products based on raw eggs[74]. The mortality of the two diseases combined is below 1 per 1000 infections (ECDC 2017). Summer months mark a seasonal peak in the number of infections. Chickens are the most common source of campylobacteriosis infections, representing up to 80% of all reported cases (Skarp et al., 2016), followed by cattle. Chickens are not affected by the pathogen. The EFSA estimates that 20-30% of campylobacteriosis originates directly from home preparation of raw chicken meat. Besides chicken, infection originates through direct contact with the animals, untreated water or consumption of infected unpasteurised milk or dairy products (EFSA, 2011). Reported cases of campylobacteriosis have been increasing over the last ten years, with poultry as its main origin. However, in the same period confirmed cases of Salmonellosis have been decreasing; they were one third lower in 2016 relative to 2008[75].

Occasionally, strong headlines are created when a specific new disease passes to man. A dramatic example in the Netherlands was Q-fever in goats (Coxiella) which caused up to 74 human deaths between 2007 and 2011[76].

The problems of AMR and zoonoses are now well-recognised challenges at EU and international level. In 2017 the European Commission adopted a new 'One Health Action Plan against AMR'[77] to preserve the possibility of effective treatment of infections in humans and animals. The plan is built on three main pillars: (1) making the EU a best practice region, (2) boosting research, development and innovation and (3) shaping the global agenda. This builds on the FAO´s 'One Health'[78] concept that acknowledges the links between human and animal health and the role played by the environment in the transmission of disease.

2.2.9. Compromised animal welfare

As the numbers of animals farmed has increased and especially as the size of business enterprise rearing animals has grown there have been increased concerns about their welfare: the way they are bred, housed, fed, treated, transported and slaughtered. Over the years many formerly accepted practices in the treatment of farm animals have come under public scrutiny and have been deemed no longer acceptable for the welfare of the animals. Examples are: tail docking of lambs, de-beaking of poultry, the tethering and treatment of veal calves, the farrowing arrangements for sows and the sheer density and method of housing and caging hens, and housing pigs and cattle. The greatest concerns are for animals raised in intensive systems which are housed full-time indoors, in high densities and with controlled and manufactured diets. It is argued that overcrowding is the most important issue in animal welfare, because it forms the basis for almost all the other issues occurring in intensive systems: antibiotic use, aggressive behaviour, and associated medical procedures and interventions to curb the damage caused by

74 It is of note that the use of vaccines in poultry to protect against salmonella saw cases in people fall by almost 50% in 2004-2009, EFSA and European Centre for Disease Prevention and Control (ECDC).

75 https://ecdc.europa.eu/en/campylobacteriosis/surveillance/atlas

76 http://www.dutchnews.nl/news/archives/2016/05/human-death-toll-from-goat-disease-q-fever-rises-to-74/

77 https://ec.europa.eu/health/amr/sites/amr/files/amr_action_plan_2017_en.pdf

78 http://www.who.int/features/qa/one-health/en/

this aggression. Other general concerns across different animal groups in intensive systems include the selective breeding for rapid weight gain to increase turnover and improve feed efficiency leading to increased breakage of bones and reduced immunity; and the separation of young from their mothers before they are fully weaned.

Animal welfare is most likely to be compromised in the following areas: overproduction, genetic selection, unnatural diets that increase growth and productivity, and handling and transport stress. These typically result in increased disease prevalence and associated animal suffering; however, these relationships have not been explored and future research efforts should provide a clearer picture of the direction needed. Over the last few years, progress has been made on improving the conditions in which animals are kept[79], transported and treated but societal awareness may ask more from the sector in the future.

The EU can claim to be a frontrunner in addressing animal welfare concerns through legislation and the creation of the EU Platform on Animal Welfare in 2017 aims to continue promoting improvements in this area. It has a long, demonstrated history of recognising responsibility to animals kept for food and other human uses. Whilst improvements can be made in this area, the EU is performing well above global standards, and the actions of individual MS is higher again in some animal welfare issues.

79 Conventional battery cages for laying hens have been forbidden in the EU since 2012. Cages are still allowed as long as they provide 750 cm2 of cage area per hen, along with other specifications (Directive 1999/74/EC).

Table 1. Summary of the beneficial and negative impacts of EU livestock

	Variable	Beneficial or negative impact
1	**Human nutrition & health**	Provides high quality protein, vitamins, minerals (Fe, Ca) and fats. However, humans can thrive on plant-based only diet. Over-consumption of animal protein is wastefully burned for energy. There is evidence linking animal fats to obesity & CHD, and certain products with cancers.
2	**Utilisation of pasture, crop by-products & residues**	Offers human food from land which can only provide cellulosic material. These supply >50% of EU livestock feed. By-products & residues provide 11% of compound feed. Grazing areas provide societal benefits: HNV farming & iconic cultural landscapes. However, land has other uses, & over-grazing degrades biodiversity, soil & landscape.
3	**Culture & livelihoods**	Humans breed, keep, celebrate, cook and eat livestock products with much enjoyment. This is deep in European culture. Livestock contribute: ~€300 b to EU GVA, 2.0% of economic output, and about 10.5 m jobs, 4.6% of EU workforce. BUT, employment cannot be justified if it is socially damaging.
4	**Climate harm**	Agriculture accounts for 10% of EU GHG emissions, livestock 60% of this, plus 25% indirect emission from crops grown for feed. 70-75% of livestock emissions are beef and dairy. Grasslands do not provide net sequestration. The EU contributes external emissions from EU feed imports.
5	**Nutrient flows: water & air pollution**	Balanced agricultural systems mix crops & livestock for nutrient cycling, rotation, weed control, soil, plant & animal health. Manure supplies 34% N & 53% P. BUT, air and water pollution, and eutrophication from excess reactive N and P are the 2nd largest negative impact (after climate). Concentration, specialisation & scale of livestock lead to deep pockets of nutrient surplus
6	**Biodiversity**	High Nature Value, low-intensity, grazing livestock contribute to semi-natural habitat & biodiversity. BUT, intensification & structural change for animals & their feed leads to habitat loss and biodiversity degradation in EU and externally. Livestock utilise 72% of EU agricultural land 50% directly & 50% indirectly. A large share of soil fertility drop, erosion, compaction therefore arises from livestock
7	**Land use and soil degradation**	Livestock use 65% of the agricultural area in the EU. While grazing can present benefits in terms of carbon storage in soils, in many areas livestock rather contribute to soil degradation through the production of feed and overgrazing.
8	**Anti-microbial resistance & zoonoses**	Antibiotic use on farm animals doubles human use, 90% for Pigs & Poultry. Risk of AMR is high, 75% of antibiotics used are excreted. Multiple risks posed. Zoonoses are diseases or infections transmitted directly or indirectly through animals & humans, 75% of new diseases have come from farm animals or products
9	**Animal welfare**	Animal welfare is regulated in the EU with five directives on housing, plus general rules. Over-crowding is behind many issues: aggression amongst animals & the procedures used to curb the damage. Concerns too about breeding for rapid live weight gain, improving feed efficiency, separating young from mothers, transport and slaughter.

3 Quantifying the safe operating space

3.1. Can we define a Safe Operating Space for EU Livestock?

The very existence of what are regarded as substantial benefits of livestock suggests that the optimal balance of the EU agriculture is not defined as having zero livestock. A proportion of the population may well choose a vegan, i.e. livestock product free, lifestyle, but patently this is a very long way from the majority societal choice in the EU. The question then becomes how to define the lowest scale of consumption and production to deliver the benefits livestock offer, and the largest scale of livestock consistent with the avoidance of unacceptable, and maybe irreversible, negative impacts. Drawing definitive judgements in this issue is complex. The challenge is multi-dimensional given there are multiple benefits and negatives. Furthermore, these variables are generally not associated with sharp thresholds or easily identifiable turning-points. They are also not independent. There are complex interactions particularly between nutrient flows, biodiversity and climate. Some variables, e.g. nutrient loads and freshwater pollution, may not have meaningful global thresholds because there is wide spatial variability in their effects with important locally-defined impacts. Yet others, like GHG emissions, have non-spatial global impacts. Some others, for example biodiversity degradation, are important both locally and globally. This combination of characteristics suggests that there is not likely for the EU, and maybe not for a Member State either, to be a definable or identifiable single optimal scale and balance of livestock which can be labelled as *the* sustainable point.

It is suggested that in this situation, a more practical approach is to try and identify *a Safe Operating Space (SOS) for livestock which can be characterised as a range of acceptable consumption and production quantities conceived, as appropriate, at the regional, national or supra-national (EU) level.* The idea of planetary boundaries and a safe operating space within these boundaries is at the core of the work of Rockström (2009) and Steffen et al. (2015). These authors identified nine variables, for seven of which they offered quantified planetary boundaries. Their results showed that mankind was already exceeding three of the boundaries, for climate change, biodiversity loss and human interference with nutrient cycles. These ideas have attracted a lot of attention and have been much debated and developed since. Raworth (2012) suggested the safe operating space as lying between a social foundation for human activity and environmental ceilings. A similar interpretation was also adopted by de Vries et al. (2013) who argued that planetary boundaries should incorporate benefits as well as adverse impacts and should focus on spatial variability of impacts. They characterised a safe operating space as a balance between human needs and adverse environmental impacts. The nature of the lower and upper boundaries of a safe operating space are likely to be different in kind. Lower limits of societal benefits or preference may be more malleable than the upper limits which purport to show what is scientifically sustainable.

The broad idea is to see if these concepts developed for global analysis of all human activity can usefully be adapted to consider a single sector such as livestock, and for a specific region, the EU. Is there a way to define and then measure the needs and the cultural and social foundations which delineate the lower boundary of the SOS and the environmental, and other e.g. ethical, ceilings to the space? Can the positive contributions of livestock in the EU be analysed in such a way as to suggest some lower bounds of a safe operating space for EU livestock production? Correspondingly, does the evidence on each of the negative aspects of livestock production offer ways to define an upper bound, or threshold or tipping point, of acceptable livestock production?[80]

This is offered as an open-minded investigation. Does this work conceptually? Can these lower and upper bounds be defined sufficiently rigorously and then quantified? Do such results lead to useful guidance for policy? These are questions this report has tried to address. The analysis proceeded in steps. It started from the simplest quite static way of thinking about these ideas, treating each variable independently. This was followed by some preliminary empirical analysis to see if it is possible to feel out the magnitudes of some of the lower and upper bounds of a SOS for EU livestock.

The analysis commenced ***with a simple static model of the Safe Operating Space***. Given the quite different considerations of each of the beneficial and negative impacts of livestock, how can the different lower and upper bounds be interpreted? As a first approximation, it is suggested that the lower bound of the SOS could be defined by the ***largest*** of the lower bounds based on the variables which measure the beneficial aspects of livestock: nutrition and health, pasture and residue utilisation, nutrient cycling, culture & livelihoods. Correspondingly, it is suggested that the upper bound of the SOS could be determined by the ***smallest*** of the bounds specified by the variables measuring the negative impacts of livestock: overconsumption, climate harm, nutrient surplus, water and air pollution, biodiversity and land degradation, AMR & zoonoses, and compromised animal welfare. At this initial stage the lower and upper boundaries are conceptualised as the overall EU production/consumption level of livestock[81].

Initially, for analytical simplicity, it is assumed that there is no extra-EU trade in livestock products and so EU production and consumption are the same. In reality, annual EU consumption and production of livestock products can be different because of (a) stock changes and (b) international trade. If current EU consumption exceeds production, then stocks of, for example, cheese or milk powder can be run down, and vice versa if there is over-production in any period. Likewise, net imports allow EU consumption to exceed EU production both in the short and long run, and net exports do the reverse. This report is concerned with the long run balance in livestock production and consumption so will not consider stock management. The issue of net trade is both an important one and a vexed and difficult subject. There are several ways to handle this issue. But the analysis here will initially park it. A high proportion (>90%) of the livestock products consumed in the EU are also produced in the EU. It is acknowledged that part of this production is based on imported feeds. There is a significant reliance on imports of protein-rich feed materials for which the EU has 61% self-supplies (Bouxin, 2017). The issues surrounding trade and the global 'footprint' of EU consumption will be taken up once progress has been made on defining, measuring and identifying policies to steer EU consumption, which is very largely based on domestic production, into its safe operating space.

In simplest form, the Safe Operating Space is illustrated in Figure 7 in which the lower bounds are measured up from zero livestock and the upper bounds are measured down from current consumption/production levels. In the purely illustrative example shown in the figure dietary recommendations feature as the largest of the three lower bounds shown and GHG emissions show the smallest acceptable quantity of livestock from amongst the variables which might define upper bounds. The space between this highest lower bound and lowest upper bound defines the safe operating space. It is interpreted as the range of EU livestock production/consumption which is deemed acceptable and durable.

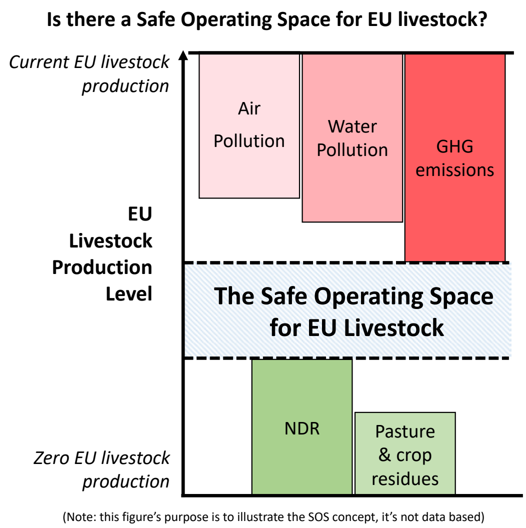

Figure 7. Defining the Safe Operating Space for EU livestock

80 The spirit in which these lower and upper boundaries are offered follows that of de Vries et al. (2013). For example the upper bounds are not to be taken as 'no effects below' and 'substantial effects above', rather as limits with uncertainties but where the likelihood of harmful effect increases where the exceedance is larger and the duration longer.

81 At this stage the analysis slips between production and consumption depending on which makes most sense for the variable under consideration. For production itself, the boundaries could be considered in total livestock units (weighting together cattle, pigs, sheep and hens appropriately), or physical tonnes of livestock product, or value of output. Whilst this obscures the important consideration of the balance between the livestock species; it is an analytical simplification to try and make progress. Subsequent analysis will have to consider the species/ product mix.

Even at this stage in developing a methodology to define a safe operating space it is apparent that some of the benefits of livestock are not easily and objectively measured. There are no lower bounds shown in Figure 7 for the benefits described in Chapter 2 as 'culture and livelihoods'. In this context 'culture' was intended to reflect the long and deeply established omnivorous diets of humans and the tendency over the last couple of centuries for livestock products to hold a strong place in diets for most people, in most meals, for most days of the week. Patently, the European population has revealed its current preference to consume the current observed quantities of livestock products. This is notwithstanding the abundant comment and evidence about the health, environmental and animal welfare harms which are associated with such consumption and production. It is not obvious how to conceptualise an objectively definable and measurable minimum quantity of livestock product consumption which satisfies Europe's 'cultural dietary preferences'.

Similarly, for the provision of private goods such as meat, milk and eggs, pluralistic market economies such as the EU do not specify a minimum consumption level and therefore correspondingly a minimum number of jobs, livelihoods and level of economic activity such goods can support. These are outcomes of decentralised consumption decisions of the population. There is no obvious way to determine a meaningful minimum level for these benefits of livestock consumption.

The cultural preference for livestock products is not absolute. Preferences can change and are subject to influence. Omitting culture and livelihoods as one of the variables defining a lower bound of the SOS is implicitly to acknowledge that in future it may not be desirable to allow free, unregulated, choice in this matter. If the negative impacts of livestock are to be reduced, livestock consumption and production levels may well be lower in future than at present, and perhaps significantly lower.

The size and ranking of the lower and upper bounds shown in Figure 7 are purely illustrative and random. They are not intended to indicate any prior guess or estimate of their relative magnitudes. Until the upper and lower bounds have been defined and measured it is not possible to say which variable indication benefits defines the lower limit of the SOS and which variable measuring the negative impacts defines the upper limit. It is also possible that the largest lower bound indicates a higher level of production than is suggested as tolerable by the upper boundaries indicated by the negative variables. This would suggest that in the absence of corrective action there *is* no SOS. Suppose for example that the ceiling, or acceptable, level of GHG emissions associated with livestock implies a quantity of livestock produced and consumed which is lower than the level which is desired to occupy the pasture areas of Europe. If this is the reality, then society must decide which is the least undesirable outcome. The options are to choose the larger level of livestock and exceed what is considered an acceptable level of livestock GHG emissions - and other sectors of land management or sectors outside agriculture would have to find a way to offset these emissions. Or society chooses to accept that the livestock population is insufficient to satisfactorily graze the grasslands of the EU so some of this would scrub over, bringing about potentially profound changes in the landscape. Of course, an empirical result of this nature would trigger scrutiny of the assumptions which lie behind the definitions and calculations of the bounds.

In effect the proposed methodology is a way of examining how to define what is meant by sustainable livestock farming. It would not be surprising if the answer turns out to be – 'not very precisely'. The situation illustrated in Figure 7 is just one of a large range of possibilities. The existence of a SOS and where it might lie can only be discovered by attempting some quantification.

Elaboration of the simple model of the Safe Operating Space. Having devised the above approach to juxtapose the beneficial and harmful effects of livestock and to conceptualise the notion of a safe operating space, it is apparent that it is too simplistic. There are quite complex relationships between the level of livestock consumption/production and the beneficial and negative impacts. Indeed for several of the variables (e.g. human consumption levels, nutrient flows and recycling, and pasture utilisation) what is a benefit at low levels of livestock can become a negative impact at higher levels. This suggests that rather than characterise each of the benefits and harms of livestock as a single calculated point, the impacts would be better expressed as continuous relationships plotted against the quantity of livestock (which could be expressed as livestock numbers or production), as depicted in Figure 8 for two beneficial and two negative impacts.

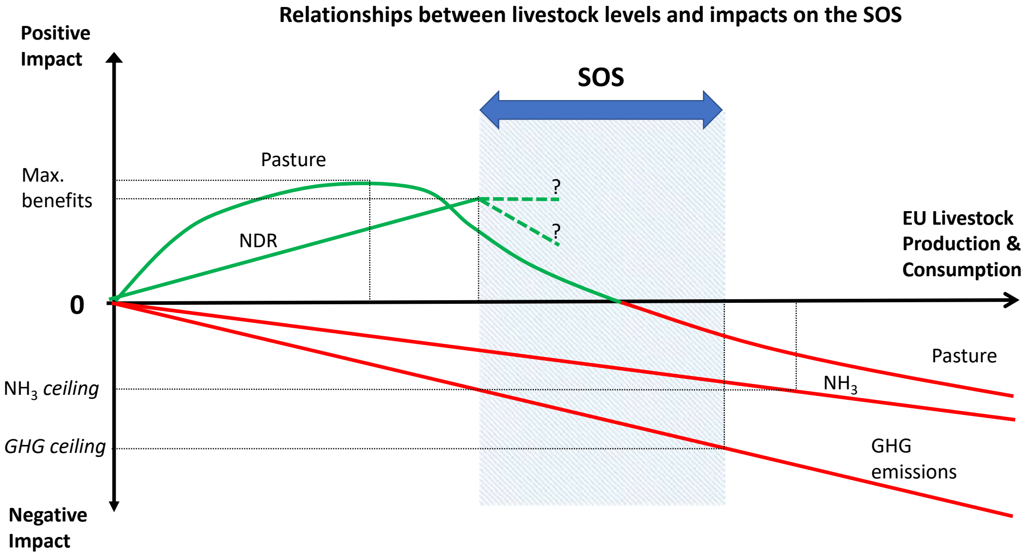

Figure 8. Relationships between livestock levels and impacts on the SOS.
The question marks denote that there is no clear consensus that consuming more than NDR levels of livestock products has the same benefits as keeping to NDR or if it actually reduces the benefits on human health.

The two beneficial effects shown are human health and nutrition, labelled 'Diet', and 'Pasture utilisation'. Details of the way these might be quantified and some preliminary results are explained below. At this point it is sufficient to suggest that for the two beneficial variables there is a relationship which is positive at least up to a point, between the dietary contribution to humans and the quantity of livestock produced/consumed. Similarly, up to a point, the more livestock, the more pasture that can be utilised. However, this relationship would be expected to show diminishing, and eventually even negative, returns as land becomes over-grazed with damage to biodiversity, soils and water quality. These relationships are shown in the upper half of the figure. The diagram goes one stage further in suggesting that there is a bound for each of these relationships. For diet the suggested boundary is defined as the quantity of livestock which supplies the amount of animal based protein specified in National Dietary Recommendation (NDR). For pasture, the lower boundary of livestock is the scale of animals which utilise the current area of grazing land at sustainable stocking densities. The larger of these two bounds in Figure 8 is arbitrarily shown as the level of livestock to provide the EU population sufficient protein and other nutrients as specified in the Nationally Recommended Diet for each Member State. This then defines the lower bound of the SOS.

The lower section of the diagram shows the relationships between the air pollutant, ammonia (NH_3) and GHG emissions and the level of livestock. These are initially depicted as simple linear relationships, with a constant rate of pollution or emission per unit of livestock. For each of these variables an upper bound is set by the ceiling level of pollution consistent with stated/legislated regulatory standards. The upper boundary of the SOS is the lower of these two bounds. Thus, the thick blue arrow shows the SOS as defined by these four variables. In principle, the analysis could be extended to include the other beneficial and harmful aspect of livestock provided their relationships can be approximated and an objective way of defining acceptable bounds for each can be devised.

A full analysis of the relationships between livestock production levels and the list of variables under consideration is a complex task. It is likely that these relationships are place, scale and farming system dependent. The interactions between the variables also should be taken into account. It is also questionable if they can all be weighted equally: the time profile of impacts is very different. The impact of biodiversity loss can last for millennia, whereas dietary recommendations and preferences can adapt in one or a few decades. The interesting question is whether there is a level of detail at which this kind of analysis can practicably be quantified, which yields insightful and useful results. This is the task of the next section.

3.2. Preliminary quantification of the Safe Operating Space for EU livestock

The chosen analytical framework requires two decisions for each variable relevant for identifying the SOS. First, a variable is defined which reasonably measures the benefit or negative impact of livestock, and second a plausible, and objectively measurable lower or upper boundary is defined and quantified for each such variable.

3.2.1. SOS lower boundary for human health and nutrition

The concept for this variable is that livestock products provide valuable nutrition for humans. The corresponding lower boundary suggested is the minimal level of livestock is that required to supply the level of consumption advised by National Dietary Recommendations (NDRs). It is not discussed whether NDR levels of livestock consumption are either, strictly necessary, or optimal for health. It is acknowledged that most human populations could exist healthily on a diet with little or zero livestock, but this is so far from current practice that it is judged it would be an inappropriate indicator of the lower boundary of the SOS. The NDRs are the official recommendations of the bodies set up to guide healthy eating. The analysis is conducted at the level of average annual per capita consumption for EU MS.[82] This idea was inspired by the work of Behrens et al. (2017) who investigated the environmental impacts of dietary recommendations. Their analysis goes considerably beyond livestock consumption as there is over-consumption of many carbohydrates including sugars. However, it is evident from their results that livestock are responsible for much of the environmental damage their study identified. That study examined current food consumption levels based on FAO data on 88 food items in 44 high and middle income countries including the EU27. It compared this consumption to the food consumption level advocated in each country's official or independent National Dietary Recommendations which are designed for good health. Then, using data from EXIOBASE, an environmentally extended multiregional input-output database (Wood et al., 2014), they calculated the impacts on three environmental indicators (GHG emissions, nutrients (phosphorus) and land use) of the consumption which they calculated is in excess of dietary recommendations.

This approach has been adapted here to calibrate the proportion of current consumption of livestock products which is necessary to meet the recommended levels in the EU. This in turn can be used to indicate the proportion of current EU production of livestock to provide this recommended dietary intake and serve as one of the indicators of the lower bound of the safe operating space.

The methodology of the calculation[83] was to calculate the actual consumption of animal products from FAO Food Balance Sheets (FBS)[84], and to compare this to livestock product intake recommended in the NDRs prepared by each of the EU Member States. The difference between actual consumption and recommended consumption is termed the dietary gap. Each of these was calculated as follows.

Actual consumption. Food supply quantity data show nationwide plant and animal products available based on EU production plus imports for 21 broad food groups. Values are adjusted for stock changes, exports, quantities used for seed, animal feed, and the manufacture of non-food products. The calculations are based on weight expressed as kg/capita/yr and focussed on animal product supplies for each of the EU28 MS, for the period 2000-2013. The data was divided into arithmetic averages for two-time periods 2000-2006 and 2007-2013. FAO supply data is provided as "primary equivalent"; therefore, the data were converted from animal products supply to the actual consumption of animal products as defined in the dietary recommendations. This conversion required two correction factors. The first factor accounts for the components not eaten and products primary conversion. (e.g. bones in meat, as meat supply in the FBS is defined as carcass weight) and the second correction is for waste by households and catering. The applied factors are those suggested by Vanham et al. (2013a, 2013b) (Table 2).

Recommended consumption. Most EU MS provide National Dietary Recommendations for consumers as part of their national health and nutrition policy. There is considerable variation in the way each country expresses their NDRs and there are often substantial differences in how the animal products are defined and in the recommended consumption quantities. In the full analysis two ways of specifying the NDRs were examined: first a regional approach in which the 28 MS were allocated to one of four regions and regional average NDRs applied[85] and second where average EU28 recommendations are used for all MS. Only the results of the second scenario are shown here. Table 2 displays the way the dietary recommendations for livestock are made. For most countries they are at a broad level, e.g. for meat as a whole. Some countries, e.g. Sweden, make qualitative suggestions about red versus white meat. Nordic countries advocate higher meat consumption, more than three times, the Mediterranean diet and more than double the dairy products. The German recommendations lie between these two for meat and milk products.

82 It is recognised that these averages hide a great deal of variation as consumption levels vary by age, gender, occupation and lifestyle. All these factors can change over time.
83 Which has been devised and executed by Natalia Brzezina KU Leuven.
84 FBS, 2013. http://www.fao.org/faostat/en/#data/FBS

85 The four regions were North (Ireland, UK, Sweden, Finland, Denmark, Estonia, Latvia, Lithuania) with the Nordic recommendations. West (Germany, Belgium, The Netherlands, Luxembourg, France, Austria) and East (Poland, Czech Republic, Slovakia, Hungary, Romania, Bulgaria)with the German recommendations used for both these regions, and South (Portugal, Spain, Italy, Slovenia, Croatia, Greece, Malta, Cyprus) with the Mediterranean diet recommendations (Vanham et al., 2013a).

Table 2. National Dietary Recommendations (NDR) for animal products in the EU.

	Scenario 1: Recommendations 4 EU zones				Scenario 2:
Group of animal products	***West*** *(based on German NDR*	***East*** *(based on German NDR)*	***South*** *(based on Mediterranean diet)*	***North*** *(Based on Nordic NDR)*	**Recommendations averaged for EU28**
Meat	450 g per week	450 g per week	200 g per week	700 g per week	450 g per week
Milk	200 g per day milk and 50 g per day cheese (400 g milk eq.): total 600 g per day	200 g per day milk and 50 g per day cheese (400 g milk eq.): total 600 g per day	150 g per day milk and 40 g per day cheese (320 g milk eq.): total 470 g per day	350 g per day milk and 25 g per day cheese (200 g milk eq.): total 550 g per day	555 g per day
Eggs	up to 3 eggs per week (1 egg 60 g)	up to 3 eggs per week (1 egg 60 g)	2-4 eggs per week (1 egg 60 g): 3 eggs chosen	up to 3 eggs per week (1 egg 60 g)	3 eggs per week

The Dietary gap. Preliminary results from this analysis are summarised in Figure 9[86]. The figure shows how meat and milk consumption in each Member State deviates from NDR levels. Data for the 2007-13 period is used.

For **meat** there is a very clear result that all MS are consuming significantly more than is recommended, on average, more than twice. The consumption level consistent with the NDR for meat for the EU28 on average is at 45% of current EU consumption. The range in this figure is from 95% for Croatia to only 40% for Spain. Because the EU average NDR has been applied, the adjustments for the northern country meat consumption to their national NDRs would be less than the figures here. But it is highly revealing that consumption in the Mediterranean countries should reduce 50% or more even to achieve the average EU recommended level, let alone the very much lower NDR their governments recommend. Mediterranean people do not seem to be consuming the Mediterranean diet! For 13 MS there has been a small fall in meat consumption on average between the two periods so a smaller adjustment is required. But for 12 MS consumption has risen between the two periods, particularly Croatia, Latvia and Lithuania, necessitating a larger reduction in consumption to reach the EU average recommended level.

For **dairy products** there is a very different pattern of dietary gaps. Seventeen MS should reduce consumption to get to the recommended levels, three of which, Sweden, Netherlands and Finland, by approximately 40%, but most should reduce by between 5% and 20%. Consumption of dairy products in most of the new MS is below the average EU recommended level, and Spain is in this group too. In some cases, such as in Bulgaria, Cyprus and Slovakia, consumption is up to 60% below recommended levels.

The results for **eggs** produce a similar pattern as for dairy products, namely 17 or 18 MS are consuming above recommended levels, with several countries showing an excess of more than 30%. Amongst the 9 or 10 countries consuming below the average EU recommendation the largest increases shown for the recent period are Cyprus, Finland and Ireland.

Conclusions on this boundary. These results can only be taken as offering the broadest of indications. Dietary recommendations are offered to the whole population, and in the context of a broad diagnosis that the major issue is overconsumption of calories and associated ill health. The NDRs themselves are mostly quite crudely expressed, for example by aggregating all meat onto one category. Dietary experts will no doubt suggest caution about focussing only on one part of the diet, even an important part such as livestock products. Healthy life depends on the whole diet and the activity and exercise regime too and dietary requirements depend also on age, gender and activity. Also, as was shown in Chapter 2, consumption patterns for the different meats and dairy products vary considerably between MS with complex cultural and other explanations. The subtlety of different dietary preferences around Europe is not embraced in this data.

Nonetheless, taking these results at face value the follow-

86 For the data refer to Appendix 1.

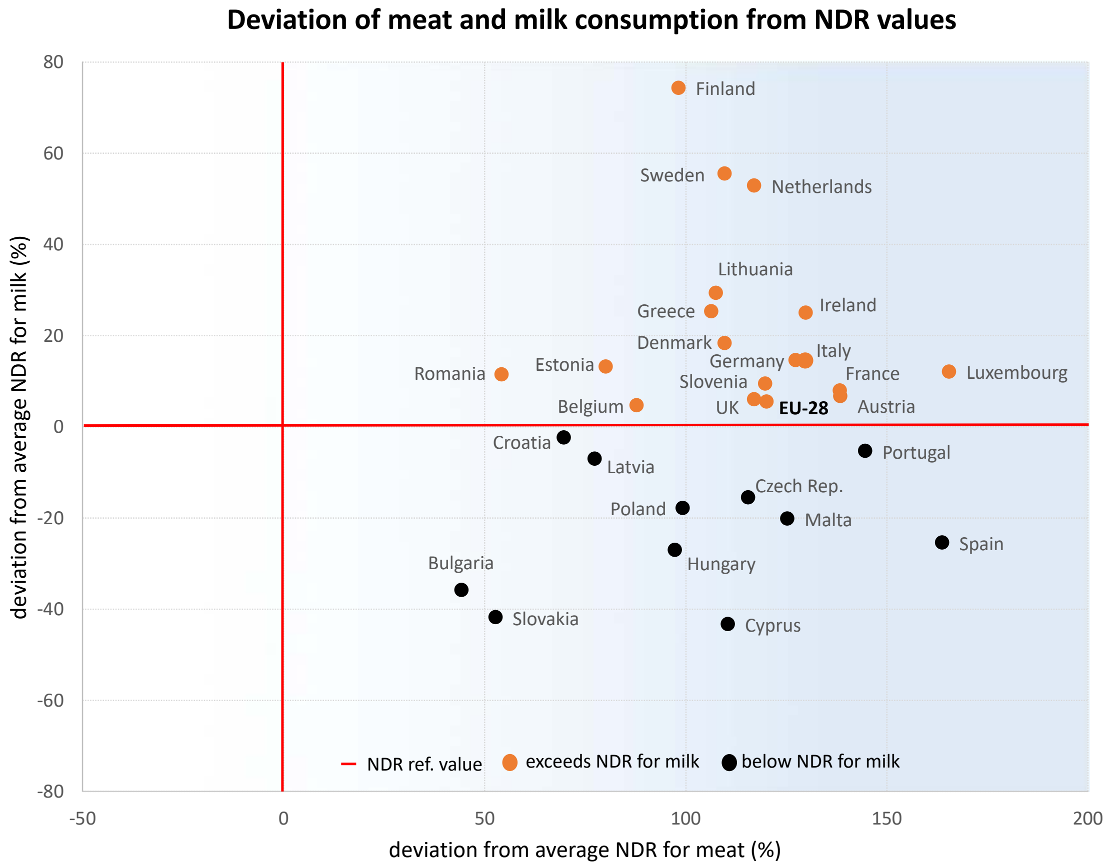

Figure 9. Percent deviation from NDR for meat and milk in the EU28 by Member State for 2007-2013 (EU28 average included)

In black, countries that are below the NDR for milk, and in orange countries that are above the NDR for milk. All countries exceed NDR recommended intake of meat. A 100% deviation means that current consumption doubles the NDR amount.

ing broad conclusions can be drawn. First, if Europeans are to follow the dietary recommendations of their health authorities they should consume less livestock product in total. Second the recommended reductions are not uniform by product nor by Member State, and are not to be applied to every individual. For meat, the calculations indicate that for twenty-two MS the production level required to supply the recommended diet is less than 50% of current supplies. For dairy products six MS should reduce by 20% or more, and another 11 should reduce by 5 to 15%. For eggs eight MS should reduce consumption by around 25%, and reductions of 10% are indicated for another eight MS. There are, respectively, eleven and nine MS who could, or maybe even should, expand dairy and egg consumption to meet dietary recommendations. The overall conclusion is that total livestock consumption in the EU is significantly above the recommended level for healthy living.

What conclusions can be drawn regarding the idea of using this data to define a Safe Operating Space? First, the wide range of average national consumption levels observed for EU Member States suggests it is not meaningful to offer an EU-wide quantification of a SOS for livestock as a single aggregate category. This exercise must be conducted separately for the main products (perhaps species, and even by type of processing) and by Member State (and quite possibly at a lower geographical level). Second, the data suggest that the human nutritional lower bound for meat is between 40% of current consumption for the countries over-consuming most and 60% of current consumption for most others. The lower bound of livestock for egg and milk consumption in the two-thirds of MS which are over-consuming is about 80% for egg consumption and 80% to 90% for milk. For other MS consumption is below recommended levels which could be taken as support for all the current consumption in those countries.

3.2.2. SOS lower boundary for utilisation of pasture

The boundary suggested for this variable was examined by considering the livestock numbers necessary to maintain grazing pastures[87] in good condition.

The lower boundary for pasture utilisation is defined as the minimum number of ruminant livestock needed to ensure the conservation of permanent pastures in the EU and the range of habitats and biodiversity associated with them avoiding their conversion into arable land, scrub, forest or even urbanisation. The unit of livestock used for this variable is expressed as a total number of ruminant livestock units (LSU), i.e. cattle, sheep and goats.[88] Such grazing enables the conversion of human non-edible vegetable protein from grasses and other forage into edible animal protein. It also helps preserve cultural landscapes, enhances soil fertility and contributes to rural economies. For this stage of analysis these co-products and services will be considered secondary benefits. In future elaborations consideration could be given to situations where these social and environmental benefits of, for example, traditional grazing systems such as the Portuguese Montado, and Spanish Dehesa are of equal or even greater weight in determining the lower livestock bound for a country or region. The calculation has been done explicitly to identify the minimum livestock justified for pasture management alone. The stocking rates used are lower than those which would generally be considered for farm production systems. The calculation is to multiply the hectares of pasture by an upper and lower range of stocking densities (LSU/ha) judged to bracket the sustainable intensity for most conditions in the EU. The resulting number is an estimate of the ruminant Livestock Units (LSU)[89] needed to preserve permanent pastures. These are compared with the current ruminant livestock populations in the EU28 and by member state to gauge the proportion of current ruminant livestock which might be justified if the aim is solely to have animals to preserve permanent pastures.

The three data elements are the current ruminant livestock units, the areas classified as arable land, permanent grassland and rough grazing, and information on stocking rates. The source is Eurostat Database using data from 2013. Current livestock numbers[90] were converted into livestock units using the conversion factors defined by Eurostat[91]. The total number of ruminant livestock units in the EU28 is 74 million LSU. Total utilized agricultural area in the EU is 174 Mha[92] (41% of the EU28 territory). Within this, there are 104 Mha of 'arable land', including temporary grass, and 59 M ha of 'permanent grassland', one third of which corresponded to 'rough grazing areas'. For the calculations presented here all the ruminant livestock are allocated to 'permanent grassland' only, excluding temporary grass.

Two values were taken for the stocking rate per hectare: 0.5 LSU/ha and 1 LSU/ha. These two stocking rates were applied to the the 'permanent grassland' area while half of these rates were applied to the rough grazing areas to account for the lower productivity of such land. There is no single agreed definition of a 'sustainable' stocking rate or the livestock rate needed to maintain a pasture. For comparison the ruminant livestock density in the EU28 reached 1.0 LSU of ruminant livestock per hectare of fodder area defined as 'permanent grassland' and also arable fodder crops, fodder roots and brassicas, forage plants including temporary grass, green maize, and legumes[93].

Results for the EU28 are shown in Figure 10. As expected, the calculated minimum number of ruminant livestock to utilise just the permanent pasture area and to do so at low stocking rates is a ruminant livestock population much smaller than at present. Compared to the current 74 million LSU, limiting grazing to permanent pasture alone at a stocking rate of 1 LSU/ha requires two-thirds of the current population of ruminant animals, 49 m LSU. Halving the stocking rate would bring this number down to one third of the current population i.e. to 24 million LSU. The large differences between actual ruminant livestock numbers and these minimal estimates are partly a result of the fact that in practice grazing animals, especially dairy cows, utilise a considerable area of temporary grass. Also, supplementary feeding of cattle and sheep is common in the more intensive systems. The difference can also be indicative of over-stocking of the land, which contributes to some of the negative impacts discussed in chapter 2, although this would need to be assessed regionally since many regions in the EU, particularly HNV areas, are currently under-grazed.

Figure 10[94] shows the figures for 27 EU member states (all but Malta). The vertical axes in the figure measures per cent change from the current ruminant livestock population. All MS except five - Romania, Lithuania, Bulgaria, Latvia and Estonia would require fewer livestock than now to utilise all permanent pasture. Under the low stocking rate

87 In this study we use 'permanent grassland' as an equivalent for permanent 'pasture' since in the Eurostat database both are referred to under the term 'permanent grassland'.
88 Future reworking of this concept should allow for other grazing animals which are not predominantly eaten in the EU, for example horses.
89 One Livestock Unit, LSU, is defined as one female, adult bovine, other animals are then scaled to this unit based on metabolic rates, thus cattle under 2 years score x LSU, cattle over 2 years are y LSU and sheep and goats are z LSU. LSU is the terminology used by Eurostat.
90 Databases: [apro_mt_lscatl] for bovine populations and [apro_mt_lssheep] for sheep and goats

91 http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Livestock_unit_(LSU)
92 EUROSTAT database [ef_lsfodderaa] (consulted January 2018)
93 Eurostat´s 'agri-environmental indicator – livestock patterns
94 For the data refer to Appendix 2

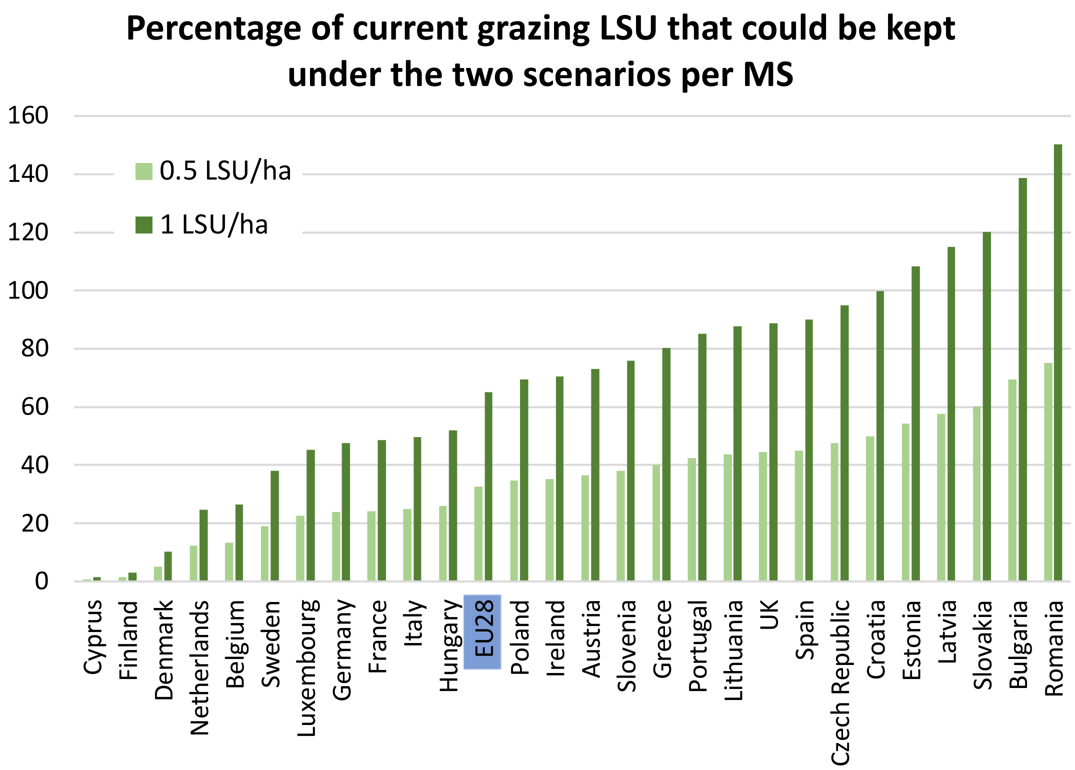

Figure 10. Percentage of current ruminant livestock that could be kept in EU28 MS if changes in minimal livestock to utilise permanent pasture at two stocking densities where applied (based on Eurostat 2013)

assumption, the proportion of current animals justified to maintain pastures are very small, less than 30% for eleven MS from Cyprus to Hungary. This group includes the three MS with the largest ruminant livestock populations (France, Germany and Italy). Another 14 countries (Poland to Slovakia) could justify from 30% to 60% of current ruminant livestock units. Only Bulgaria and Romania could justify two-thirds or more of their current ruminant animals if the lowest stocking density correctly defines the sustainable intensity.

With the higher stocking rate of 1 LSU/ha the livestock populations justified to maintain pasture are, naturally, much larger. However, these are still less than 10% for Cyprus, Finland and Denmark. Even the Netherlands can only justify 25% of its current ruminant LSUs. There are, however eleven MS (Poland to Croatia in Figure 10) which could justify between 60% and 100% of current populations. There are five countries, Estonia, Latvia, Slovakia, Bulgaria and Romania which could expand their ruminant livestock populations on these calculations.

These calculations are highly simplified, they take no account of the large differences existing between pastures and farming systems and their capacity to support ruminant livestock. Also, by merging all ruminant livestock into 'livestock units' it does not account for the different roles, and different cropping styles, played by cattle and small ruminants in the diverse grazing environments found around the EU.

The numbers of ruminant livestock 'justified' in the calculation to this point, especially using the low stocking density assumption, could be considered as low estimates of this lower bound of the safe operating space. This is for three reasons. First, more research is needed to define sustainable stocking densities more precisely for the quite different grassland areas and systems in the EU. Second, the calculations to this point do not include the utilisation of any temporary or rotational grass. Yet the move to mixed farming with implied crop rotation including pasture land and fodder crops is emphasised by those advocating organic and agro-ecological farming systems. These two additional considerations would tend to increase the estimated scale of livestock suggested by a pasture boundary. The quantification also has focussed on numbers of livestock units, rather than the tonnage of edible livestock product as was described in the nutrition calculation above. Conversion of livestock numbers into tonnes of product is also complex and should bear in mind that the calculations in this section assume the livestock are being reared parsimoniously at low stocking density with no assumed supplementary feeding.

In addition to grazing on pasture, livestock are also fed residues and by-products from food processing industries. Utilising these materials could be another way of justifying the keeping of livestock. Making calculations of the scale of livestock which might be justified this way is not straightforward. A direct translation of the volumes of these various residues and by-products into livestock units is difficult because animal feed contains a wide range of components to meet the needs of animals: energy, amino acids, vitamins, minerals and fats. Therefore, the nutritional profile of each such product must be considered. Such materials are unlikely to provide a complete ration, so feed supplements would be required to meet animals' needs. While the utilisation of permanent pastures can be largely independent of other sectors, this is not so for by-products and residue. These are blended by feed compounders with other standard ingredients as dictated by market conditions. The main source of by-products for feed production in the EU is currently the biofuel industry, providing 12.6 Mt[95] of feed annually (dry matter). The development of the biofuel industry goes therefore hand in hand with the demand of livestock feed for its by-products. By 2020 it is estimated that by-products from the biofuel industry could displace up to 38% of current soybean meal use (Lywood and Pinkney, 2012) if the biofuel industry continues to expand. These by-products from the biofuel industry come from EU cereals, sugar crops and oilseeds. Mixes of such by-products from cereals and rapeseed meal can partially displace a soybean meal in monogastric feed. Such oilseed meals can have a protein content higher than the optimal range in animal feed, so they are blended with cereals (lower in protein content) to reach an optimal protein concentration in feed (Lywood and Pinkney, 2012). Such substitutions were supported by the agriculture committee in the European Parliament[96].

In 2014, 3.3 Mt of 'valuable animal feed' was produced from bioethanol co-products, which Farm Europe suggested could feed 2.1 million dairy cows (10% of EU herd)[97]. This does not explain if these animals were only supported by such feed. In a global study, van Zanten et al. (2016) estimated the hypothetical amount of meat and livestock products which could be produced from grazed biomass plus by-products and wastes, to be 21 g/person/day[98] of animal protein. This is about one third of the recommended amount for human nutrition. More work is required to quantify the volumes of such material available and the mix and numbers of livestock including monogastrics which could be justified in the EU to make use of these feed materials.

Conclusions on pasture. A conservative estimate is that about half of the current ruminant livestock in the EU could be justified in their role of making use of the available permanent pastures, including rough grazing. There is a wide range around this average in the individual MS. These figures could be higher if account is taken of temporary grass, crop residues and by-products[99]. It is emphasised that these are crude capacity estimates and do not take account of the economic viability of livestock grazing enterprises operated in the suggested range of stocking densities. This raises quite different considerations.

3.2.3. SOS upper boundary for climate protection

There is general agreement that the most firmly established planetary boundary is climate change. Tipping points have been established showing how irreversible temperature change, sea levels and extreme events can have catastrophic effects if the accumulation of GHG in the atmosphere is not halted and reversed. The contribution of livestock to GHG emissions is large and growing. Together with the related concern of nutrient flows this is suggested to be the foremost consideration defining what should be an upper boundary for livestock.

The assessment GHG emissions from EU livestock presented here is based on the emission accounting data as available in Eurostat for 2013. This follows the IPCC conventions which measure emissions at source and for agriculture includes the mostly non-CO_2 emissions of methane and nitrous oxide. For the EU28 in 2013, 78% of agricultural emissions were from livestock. However, these figures for livestock emissions do not tell the whole story, they do not include the nitrous oxide associated with EU crops fed to livestock, nor the emissions from imported feeds. The analysis which follows therefore could be viewed as a significant understatement of the challenge.

95 According to Farm Europe
96 http://www.europarl.europa.eu/news/en/press-room/20171002IPR85147/boosting-share-of-food-friendly-biofuels-in-the-eu-s-energy-mix
97 http://www.farm-europe.eu/travaux/poducing-fuel-and-feeds-a-matter-of-security-and-sustainability-for-europe/#_ftn25
98 They estimate permanent pastures and meadows to produce 7g/person/day, food waste to represent 10% of total food production and by-products and food waste to produce an annual amount of 14 g of protein per person per day. http://edepot.wur.nl/380267
99 In the current calculations, the benefit sought is the maintenance of pastures for landscape and biodiversity purposes. Another scenario could be to maximise the conversion of non-edible feed into edible food (e.g. the use of pasture, residues and by-products). Some preliminary calculations for this were made for the pasture use (using 1-2 LSU/ha)) but the challenge of how to convert quantities of by-product (including co-product) into the number of livestock units that they are able to support was not satisfactorily resolved. Also, it can be questioned whether livestock feeding only on by-products could provide a balanced diet.

The analysis starts by looking at the past performance of EU livestock emissions. Data on emissions for 2013 were compared to 1990 to evaluate progress against the Kyoto protocol reduction target of 20% by 2020. Total GHG emissions in EU28 agriculture decreased by 22% over this period, but with very unequal contribution across countries ranging from a 4% reduction in Spain to a 55% reduction in Bulgaria. Indeed, all the former centrally planned MS (except Slovenia) showed emissions reductions since 1990 of over 35%. This reflected the general contraction in both crop and livestock production that these countries experienced as they made the transition to the market economy. Livestock emissions show a slightly larger reduction for the EU28 by 24%, again with widely different contributions ranging from zero reduction in Spain to a 68% reduction in Bulgaria, and similar large cuts in the other former Soviet bloc countries. Most of the reduction in livestock emissions is explained by the fall in animal numbers especially cattle. There are also large differences between the more livestock-oriented countries. There have been relatively small changes in Denmark (-4%), Ireland (-7%) and France (-9%) compared to the much larger changes in Belgium (-16%), the Netherlands (-18%) and Germany (-27%).

Three-quarters of the direct livestock emissions are made up by enteric fermentation and the rest by manure management. Of the enteric fermentation 83% is from cattle and 11% from sheep. Pigs and poultry account for just 6% of livestock enteric fermentation emissions. Of the 25% of livestock emissions from manure management, 44% are from cattle, and the next largest share is from pigs contributing 35%. The 24% reduction in total livestock emissions is made up by a 24% reduction in enteric fermentation emissions. The rate of fall in these emissions is approximately the same for cattle, sheep, pigs and others. Likewise, the emission reduction associated with manure management is 25%, but here the differences between species is larger, and this differs by country. While for the EU as a whole the reductions for cattle and pigs were almost the same, improvements were larger for cattle manure management in Belgium, Germany, Spain, France, while improvements were larger for swine manure management in the Netherlands. In some cases, emissions related to manure management even increased.

Superficially, it appears that the overall reduction targets for 2020 will be achieved for EU agriculture[100]. However, this is a misleading conclusion; 57% of the reduction of livestock emissions in the EU28 were contributed by ten new MS who in 2013 only account for 18% of EU livestock emissions. This came about mostly because of the extraordinary, and unlikely to be repeated, large contraction in livestock numbers in those countries during their transition to the market economy. At the heart of the calculations of livestock emissions are livestock numbers multiplied by emissions factors which are specific for each species of animal, and Member State. Some MS have the resources (and motivation) to measure and adjust their emission factors as efficiency of production improves and the emission factors decline. However, the EEA reports an increase in emission factors per cattle head, larger per dairy than non-dairy cattle that seems to indicate that emission factors are not improving (EEA, 2017b).

This is a critical issue because in future the calculated emissions from livestock can only fall if either livestock numbers are cut or if the emission factors per head are reduced as animals are bred, fed and managed to reduce emissions. The scientific measurement of these emissions with data which fully reflect the realities, and inherent variability, of managing animals in the field is a complex and expensive task.

Turning to the future and establishing an upper boundary, GHG emissions are the one issue for which there is abundant scientific evidence of the existence of a planetary boundary and an internationally agreed policy framework for action. This includes target emission reduction commitments for GHG for 2050 and intermediate targets for 2040 and 2030 with the aim of limiting average global temperature rise to below 2°C. The EU emission reduction targets for these three dates are 80%, 60% and 40%. For practical and political reasons, agricultural emissions are not formally included in these targets. It is recognised that agricultural emissions and the agricultural sector are different in kind and require actions quite different to the solution of decarbonising fuel which applies to most other sectors. However, these targets are used here to send the signal of the scale of adjustment needed if agriculture, and specifically livestock, emissions are not gradually to become a larger share of remaining emissions as energy supplies are decarbonised.

Figure 11[101] shows the scale of percentage reductions from 2013 in direct livestock emissions required by each EU Member State, and the EU28 in total, to reach the targets for 2030, 2040 and 2050, if livestock are to contribute the same as other sectors[102]. This shows the average EU28 reductions required are 21%, 47% and 74% respectively for the three dates. Because emissions in the ten central and eastern MS have fallen so much since 1990 these countries have space to expand their livestock emissions and remain within national target at 2030. The range in reductions required for 2030 for the other MS is from 18% for Germany to 47% for Cyprus. With respect to the 2040 target, only Bulgaria, Slovakia, Lithuania and Latvia have any further scope to expand livestock emissions, the

100 EC, 2013. COM(2013) 698 final

101 For the data refer to Appendix 3

102 To be clear, the reduction targets are measured from 1990 but the required remaining adjustments shown in Figure 12 and in the text are changes from 2013.

reductions for the other 24 MS range from 12% for the Czech Republic to 65% for Cyprus. To reach the 2050 target of 80% reduction, all MS must reduce emissions by between 37% (Bulgaria) and 82% (Cyprus).

This is an extremely challenging task. The experience to date in reducing emissions by improving efficiency of livestock production and doing this in a sufficiently robust and sustained way that scientifically approved emission factors can be reduced to reflect the efficiency gain, is slow. There are reasons to expect a higher rate of improvement in livestock efficiency in future. First because the scale of the climate challenge is now better understood and accepted. Significant public and private research resources are now being deployed to find ways to reduce methane production in cattle, and to better manage manure, including processing through anaerobic digestion. Second, agricultural policy support systems are paying overt attention to helping farmers adopt practices and technologies to reduce emissions, and food chain participants are engaging in this effort too. There are examples where agricultural challenges have indeed been successfully responded to by this combination of awareness raising, research and development and policy help. Two examples are: reductions in antibiotic use in Scandinavia and the Netherlands, and pesticide use in horticulture. However, it remains to be demonstrated that the improvement in future livestock efficiency will be enough to meet the pressing climate targets.

To reduce emissions sufficiently to reach the 2050 target entirely by efficiency improvement would require a sustained annual gain (i.e. reduction in the emission factors) of about 3.5% per annum. A 2.5% annual rate of reduction in the emission factors would enable achievement of the 2040 target. Such rates of productivity improvement have not been seen in western agriculture for a very long time, and never sustained over a period of decades. **The conclusion is** that if GHG emissions from livestock are to be reduced in line with the internationally agreed targets then this will necessitate a mixture of efficiency gain reduction in livestock numbers too. That is less livestock production and less consumption of livestock products. The alternative is that agricultural emissions will occupy a steadily larger share of remaining emissions.

3.2.4. SOS boundary for nutrient flows

The flows of the two critical macro nutrients in agriculture, nitrogen and phosphorus, are identified by Rockström et al. (2009) as planetary boundaries which are

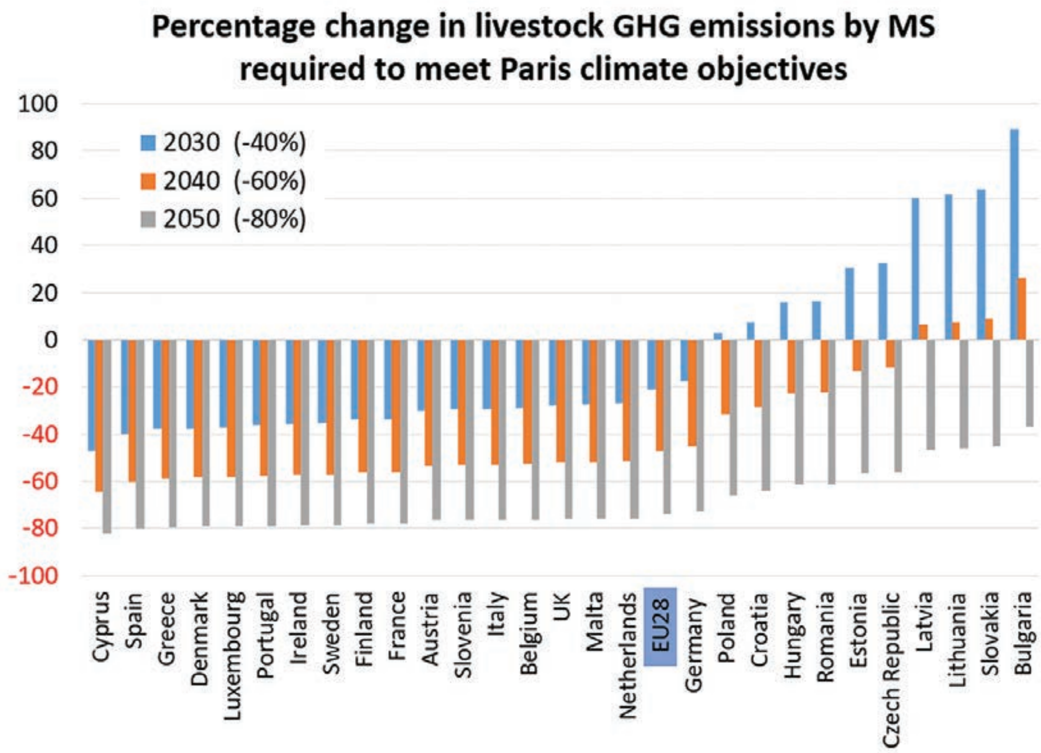

Figure 11. Scale of percentage reductions from 2013 in direct livestock emissions required by each EU Member State, and the EU28 in total, to meet Paris targets – if livestock are to contribute the same as other sectors

already being exceeded. The consequences show up as serious water pollution, leading to eutrophication of terrestrial and marine ecosystems, and also contributing to climate change. De Vries et al. (2013) discuss the complex mix of global and regional effects of nutrient imbalance and conclude that it is important to disaggregate analysis to regional level and thus speak of regional boundaries. They point out that this is not new, it has been common place to define regional boundaries in environmental policy for example in dealing with geographically defined critical loads for sulphur deposition.

To demonstrate the orders of magnitude of adjustment necessary to deal with nutrient imbalances the analysis is conducted at EU Member State level. It is readily acknowledged that for large Member States a sub-national regional approach is desirable because there is wide spatial variability in nutrient flows and the resulting excesses. Policy action to move livestock to its safe operating space must operate at the most relevant geographical level. Indeed, EU nitrates and water framework directives work at the level of river basins.

The preliminary analysis conducted for this study focuses on nitrogen. A fuller analysis must complement this by looking at phosphorus. There are differing views on which of these nutrients defines the lower boundary for livestock. The variable used here to measure nutrient flow is nitrogen fixation and the analysis is conducted at the EU Member State level. Country level data on N flows in 2013 were taken from the Eurostat database. N fixation is the sum of fertilizer consumption and biological fixation.

The next step is to define an objectively determined upper boundary for N fixation for the EU and the Member States. It became apparent that establishing this boundary is an area which is still developing amongst the research community. The planetary boundaries related to biogeochemical flows (specifically N and P cycles) refer to the excess amounts of reactive N and P that are released into the environment. For N, the four main sources are: industrial fixation of N_2 into ammonia, biological fixation via agricultural leguminous crops, the combustion of fossil fuels and the burning of biomass (Rockström et al., 2009). The global N boundary was defined by Rockström et al. (2009) as "*the human fixation of N_2 from the atmosphere as a giant valve that controls a massive flow of new reactive N into the Earth System. The boundary can then be set by using that valve to control the amount of additional reactive N flowing into the Earth System*". It was initially set at 35 Mt N yr^{-1}, but — following criticisms by de Vries et al. (2013) that this boundary does not take human needs into account — it has been revised to 62 Mt N yr^{-1} (Steffen et al., 2015). To downscale this global boundary to the country level, an allocation criterion is required. Kahiluto et al. (2015) downscaled the boundary on a simple per capita basis for the human population. This leads to a per capita boundary of 8.6 kg $capita^{-1}$ yr^{-1} based on a global population in 2013 of 7.2 billion. The boundary for each EU Member State was therefore calculated as their 2013 population times 8.6 Kg N.

N fixation thus corresponds to this definition of the N regional boundary. Of course, part of the N fixation is not related to livestock production, but to crop production. The disaggregation of N fixation into crop production and livestock production (including crops produced for livestock) is not available in Eurostat, and would require detailed calculations that go beyond this exercise.

In an ideal world, the nitrogen (and phosphorus) added to soils annually would exactly match the requirements of crops, with zero leakage to the environment. This is not possible. Nutrient availability for plant uptake is not simply a matter of nutrient concentration in the soil. Nutrient uptake by roots as plants grow is a complex phenomenon which depends on many factors: soil structure and composition, soil microbes, rainfall and thus moisture content, temperature, pH, cation exchange capacity. In commercial cultivation practice there will inevitably be a positive nutrient balance – i.e. more nutrient is applied than is taken up – in agricultural soils. Indeed, negative soil balance, which is seen in developing country agriculture, is inevitably associated with low crop productivity calling for higher nutrient application. The question is what is the minimum such net balance consistent with feeding the population its nutritional requirement for health life and yet not over-loading terrestrial and marine ecosystems?

It became clear that working from the planetary level downwards there is, to date, no scientific, well-established upper boundary for N flow as an environmental limit. The logic of de Vries and Kahiluoto seems to turn this round and seek a lower boundary of the lowest N flow which could be necessary to provide the protein necessary for humans to survive and thrive.

Given this per capita N allowance, and accepting that much of this allowance should be supplied by plant protein, the adjustments in EU Member States implied by respecting this lower limit are likely to be large. They are! The comparisons between the current N fixation and the estimated boundary for each Member State are shown in Figure 12[103].

For two Member States, Malta and Cyprus the calculated boundaries based on population needs is much larger than the current annual fixation. This approach clearly is not helpful for these special cases. For the 26 other Member States, and for the EU28 the annual N fixation associated with livestock considerably exceeds the estimated boundary. The EU28 excess is 65% of current fixation. The

103 For the data refer to Appendix 4.

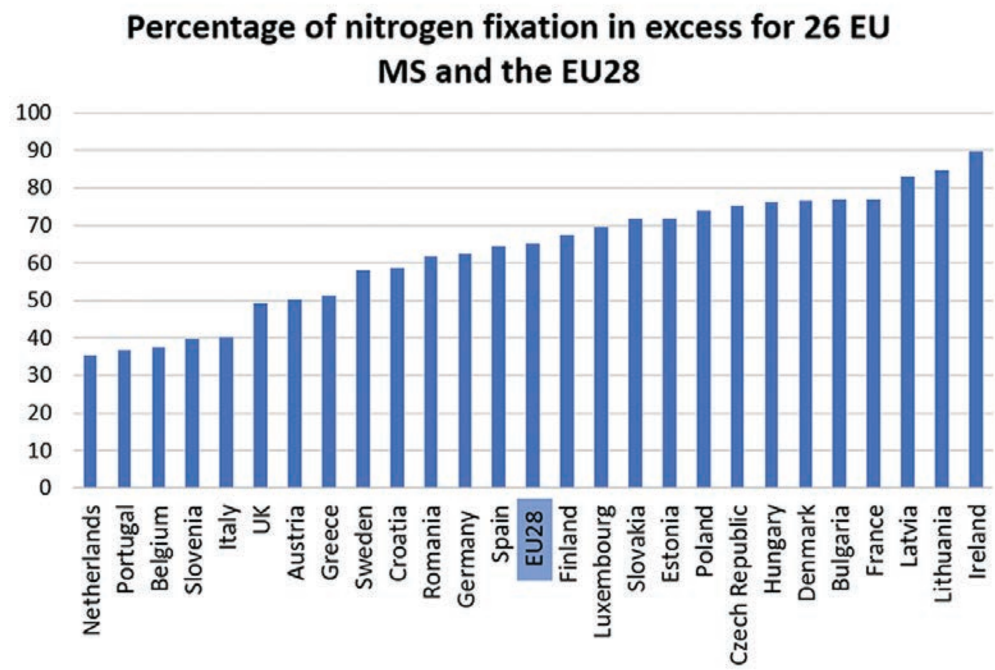

Figure 12. Percent of nitrogen fixation in excess of the calculated boundary for 26 EU Member States and the EU28 (data from Eurostat for 2013)

percent excess for the Member States ranges from 35% for the Netherlands to 90% for Ireland. It is greater than 50% for 20 Member States and over 75% in eight MS.

These are highly aggregated results which must be interpreted with care. The national nutrient surpluses shown for the Member States hides the fact that these excesses are very different across the territory of the Member States, this is clearly indicated in the nutrient surplus maps which are calculated by comparing N applications (summing manufactured fertilisers, manures and estimated biological fixation) with the estimated off-take in crops and animal products, an example of which is shown in Chapter 2. The fact that the Netherlands and Ireland are at opposite ends of the figure indicates that the national figures on total N balance tell us little about the regional concentration of nitrogen.

There is an important difference in the challenge of adjusting livestock to within its safe operating space for nutrients compared to greenhouse gases. For GHG the boundary is non-spatially significant so there are just two strategies available: to improve production efficiency, and to reduce animal numbers (and thus, most likely, total output and thus consumption of livestock). For nutrients, the boundary is spatially significant so there are further options available. One is de-concentrate production another is to export manures in raw or processed form. The latter is commonly practiced, for example poultry manure form the Netherlands is exported to the Eastern lander of Germany and to vineyards in France. Provided such flows are not disturbing nutrient balance in the receiving regions such trade should be embraced by definitions of the SOS. The deconcentration option is to encourage livestock production itself to relocate to crop production areas which tend to be in nutrient deficit areas which import mineral fertiliser and manure. However, whilst the GHG boundary is time defined by the Paris Agreement emission reduction targets and seems to offer an adjustment path over three decades, the exceedance of the nutrient boundaries is already present. There is greater urgency to address it now.

Conclusions on the nutrient flow boundary. The quantification of an upper boundary for nutrient flows clearly requires more work. This study set out to find an upper, environmental, boundary and discovered what might more accurately described as a lower dietary boundary. Indeed, it suggests a level of activity much lower than that produced from the National Dietary Recommendations. It would be interesting to pursue the quest launched by Rockström for a plausible global environmental boundary which can then be disaggregated to national and regional level. However, it is likely to be more useful to work in the opposite direction and define regional (river basin) boundaries based on environmental legislation and find a way to translate these to feasible livestock densities and populations. Given the damage that its leakage does to water (and atmosphere) the ultimate target must be to minimise annual nitrogen accumulation, and thus to minimise the causal activities, chief of which is livestock production. A further necessary step in the analysis is to consider whether a combination of improvements in nitrogen (and phosphorus) use efficiency and relocation and de-concentration could be sufficient to bring usage within the boundary. If not, it will be necessary to reduce the overall scale of livestock production and consumption.

3.3. Pulling the preliminary results together

The previous section has suggested simple ways to help quantify boundaries of the SOS for livestock based on National Dietary Recommendations, pasture utilisation, GHG emissions and nutrient flows. Before drawing conclusions on these attempts to delineate the SOS, the possibilities of deriving SOS boundaries for the other impacts of livestock are reviewed.

3.3.1. Are there boundaries for the other impacts of livestock?

It is suggested that that it is not possible objectively to determine a minimal level of livestock consumption for the purpose of **creating livelihoods**, i.e. economic activity, employment and communities. That livestock consumption creates a wide range of professions and occupations is beyond doubt. A selection of those most directly involved in the livestock food chain includes: the input providers – feed ingredient traders, millers, compounders, distributors, fertiliser and machinery manufacturers, animal health product providers, veterinarians and animal breeders. On-farm are found – farmers, graziers, shepherds, stockmen, milkers and shearers. Livestock product occupations downstream include – slaughterers, tanners, dairymen, milk and meat processors and distributors, butchers, chefs, waiters and retail staff. These include long-established and honourable professions. To perform their roles, many of these practitioners acquire and pass on considerable knowledge, experience and skills. In the market economy, the numbers in such occupations are the outcome of consumption choices, and technology. There is no rational way of determining the correct, or minimal number of such jobs. If consumption grows, employment and economic activity in these sectors will grow, but if livestock product consumption contracts then it is likely that jobs and activity in this food chain will contract, although jobs could grow in other parts of the food chain. This is the reasoning leading to the conclusion that no objective minimum employment or economic activity can be defined *ab initio*.

No progress has been made on quantifying the boundaries for the other variables on which livestock production has significant negative impacts, **biodiversity, land use and soil degradation, anti-microbial resistance and**

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zoonoses and animal welfare. Considerable effort is expended on assembling indicators of some aspects of biodiversity, particularly farm land birds, but also latterly on insects, especially pollinators. There are comprehensive statistics on land use. There is information available on soil erosion, compaction and organic matter loss, but as these are highly location specific and not simple to measure the evidence base is slender. There are also good data on antibiotic use and on animal disease incidence. There is less systematic data measuring the status of animal welfare. This is conceptually difficult to measure and not easily inferred from data on the structure of livestock holdings.

For all these variables, there is no doubt that they raise critical concerns about livestock product consumption and production. Indicators of the scale of the (mostly negative) impacts that livestock production has for most of them are available. However, there is no obvious objectively measurable criterion which defines an upper boundary of sustainable and thus acceptable impacts. More thought is required to discover how to characterise their relationship to the Safe Operating Space defined by the variables for which variables and plausible boundaries can be found. However, it seems reasonable to suggest that actions to bring livestock within the upper boundaries for climate and nutrient flows are likely to provide relief for these other variables.

3.3.2. Conclusions on Livestock's Safe Operating Space

First, some **general conclusions** are offered.

The concept of a Safe Operating Space is a useful addition to the difficult debate about agricultural sustainability. It was also felt important that the positivity of the phrase 'safe operating space for livestock' offers some comfort and encouragement for producer interests to work constructively to discover this space. However, and perhaps unsurprisingly, it transpires that it is not much easier to pin down the SOS than it is to conclude whether an activity is sustainable. Investigating the SOS poses analytical questions to which some empirical answers can be given. The characteristics of the upper and lower boundaries are quite distinct. It emerges that there are reasonable prospects of being able to identify robust, scientific upper boundaries for the SOS, which if exceeded lead to serious consequences. However, the lower boundaries are more culturally determined. If they are not reached the consequences are dissatisfaction but not system collapse.

It was acknowledged in Chapter 2 that, strictly speaking, none of the benefits of livestock are absolutes. They are best characterised as strong cultural preferences in current European society. The sheer quantity of livestock product consumed is a relatively recent phenomenon and so the lower boundaries are amenable to influence

and change. This means that it is not possible to establish objective, scientifically-determined, lower limits for livestock to help define the SOS; such minima do not exist. Sections 3.2.1 for human nutrition and 3.2.2 for pasture utilisation suggest ways in which current EU preferences for consuming livestock and for managing the cultural landscape of rural areas can be at least roughly quantified. The results are expressed as the proportion of existing consumption, or of existing grazing livestock numbers, which can be justified to minimally satisfy these preferences. These results are offered as indicators of direction of adjustment and orders of magnitude of benefit and are not intended to be definitive guides to policy.

The role of farm animals in cycling manure and the correct way to depict this contribution in defining the SOS deserves more discussion. It is seductive to see the cycling of nutrients animal manure as a strong benefit of the livestock sector. It is held up as a prime exemplar of the circular economy in action. As this practice has been established over centuries of traditional farming it might viewed as a beacon for the way ahead. However, a closer look reveals a much more qualified story. All the while farmed animals are a part of agricultural systems then it is critical that as much as possible of the nutrients that they ingest and which is not converted into food for human consumption, is recovered and reused. However, short of hermetically sealing animals into contained production units from which all gaseous, liquid and solid matter can be collected, and processed to extract the critical nitrogen and phosphate, some of these nutrients, in fact an alarmingly high proportion, will find their way into the environment. These leakages will end up in water bodies, the air and the atmosphere and in all three media their accumulation is seriously damaging. But equally there are limits to the containment of animals set by the welfare standards that society will tolerate.

To put it another and stark way, scientifically the lower bound for the nutrient cycling benefit offered by livestock is zero. No livestock farming would mean no leakage of nutrients from livestock. It might seem tempting to calculate the minimal livestock population which could provide the nutrients for a wholly organic crop production sector part of which feed the animals. But this makes no sense. Nutrient use efficiency in the food system would be higher if there were no intermediary animals but rather a fraction of crop biomass, plus crop processing wastes, were composted and cycled back to maintain fertility for future production[104]. Cycling nutrients through animals is not a first-best solution. However, all the while animals are kept then it is wise to recover and reuse as much nutrient as possible.

Patently the fierce logic of zero lower limits for livestock is not in general application in the developed world. Humans over recent centuries, and particularly in recent decades, have developed a strong capacity and cultural preference for consuming more livestock products. The bulk of these products are now produced in modern rather than traditional ways. At the same time there is strong appreciation of traditional livestock technologies and the associated rural communities and cultural landscapes which are in danger of disappearing. This is a difficult dissonance or imbalance to resolve. The lower boundaries suggested, based on dietary recommendations and pasture utilisation are offered as pragmatic indications of lower bounds for the safe operating space. They suggest that in the region of 60% or more of current production might be justified. As the sternest of livestock's critics are 'only' asking for contraction of 60% to 70% of EU livestock (Tirado et al., 2018) this means that for the foreseeable future there will continue to be substantial production of livestock and therefore the recovery of nutrients and cycling of animal manures (and human waste) back to crop production will continue and it is vital that it is done in the most efficient, least leaky way[105].

More specific conclusions

This study set out to test the idea that it would be useful to identify if there is a safe operating space for livestock and to broadly indicate the direction and some orders of magnitude of the adjustments which might have to be made to bring the sector to its SOS. The concept of a safe operating space was inspired by, and builds on, the work of Rockström and his team in their identification of planetary boundaries for the totality of human behaviour. It is consistent with the drive to achieve the sustainable production and consumption of food contained in the Sustainable Development Goals.

One of the first findings from adapting this mode of analysis to livestock in the EU is that not all the critical variables identified lend themselves to defining a lower or upper bound. The approach seemed workable in providing lower bounds based on human nutrition and health, and utilisation of pasture. Some progress was also made in investigating upper bounds based on avoiding climate harm. It proved more difficult to discover established boundary definitions of the limits of nutrient overload. Time and resources precluded any progress being made on biodiversity degradation and land use and degradation. It was concluded that there are neither suitable metrics nor obvious ways to define lower or upper bounds for the other three variables: culture and livelihoods, AMR and zoonoses, and animal welfare. It might be supposed that a reduction in livestock to get into the SOS defined by GHG and nutrients might also have beneficial impacts in reducing use of antimicrobials and incidence of zoonoses, however this cannot be taken for granted, it depends on the species and nature of such adjustments. Table 3 below summarises the boundaries considered and the preliminary results gathered.

The analysis has not made formal distinction between EU levels of livestock product consumption and levels of domestic production because a high proportion of EU production is domestically consumed. There has also been no attempt to convert the variables listed in Table 3 onto a common metric of animal numbers or quantities produced, nor to suggest how the totals might be allocated between the main species. It is suggested that these are second order considerations which will only be confronted if there is acceptance of the principal conclusions of the analysis to this point.

These are:

1. EU livestock production and consumption are not in their safe operating space.
2. Current EU livestock production is associated with greenhouse gas emissions and nutrient flows which are currently far higher than the upper boundaries of the SOS and is therefore unsustainable. Reductions in these leakages of the order of 60% or more are indicated.
3. Current livestock consumption and production are considerably greater than the lower boundaries of the SOS based on national dietary recommendations and on pasture utilisation. Also, the boundaries established for these two variables imply production levels greater than those required to respect the upper boundary for GHG emissions.
4. These findings imply uncomfortable choices for society. However, it is clear that respecting the upper environmental limits should take precedence over the cultural lower boundaries.

Two broader conclusions also emerged from this analysis. First, truly global boundaries are rare; GHG emissions and climate change provides the principal example. For most other variables, global or even national averages are not

104 It is a separate question whether sufficient crop production can be achieved in this way or whether supplementary mineral fertiliser is justified.
105 This was the theme of the RISE Foundation report 2016, Nutrient Recovery and Reuse in the EU.

meaningful and boundaries for such variables must be established at a more relevant geographical level. Even when this is the case it is still useful to compute and refer to the EU and national boundaries and how much they are over-shot or under-shot because this will be usually necessary to galvanise EU and national policy action. Some variables, such biodiversity have elements of both global and locally specific aspects.

Second, although the analysis has been conducted treating the variables as independent, there are important interactions between them. Some will tend to move together in the same direction. For example, increasing the overall volume of livestock production has tended to be associated with increased GHG emissions and increased nutrient flows, and large impacts on biodiversity and soil degradation. As livestock intensity increases as measured by more and faster live weight gain per unit of feed for pigs and poultry, or milk yield per lactation per cow, this can improve resource efficiency thereby reducing GHG and other emissions per Kg of product. However, it also can, and it is stressed 'can' and not necessarily 'will', run counter to animal health and to acceptable animal welfare.

These features, together with the multiple species of livestock and their multiple different production systems and consumption profiles, rule out the idea that there may be a discoverable socially optimal level and makeup of livestock. This leaves us with the wider, but less definitive concept of a safe operating space with only quite broad indications of whether current production and consumption are in this space. The next chapter examines a range of actions to take the EU into its SOS for livestock.

Table 3. Progress in measuring boundaries of the safe operating space for EU livestock

Impact of livestock	What variables to measure impacts?	What defines the (L) lower or (U) upper boundaries?	EU28 result
1. Human nutrition & health	Human daily intake of animal proteins	(L) National Dietary Recommendations	**Lower bound:** Meat: 65% of current consumption, milk 80-90%, eggs 80%
2. Utilisation of pasture, crop by-products & residues	Grazing of permanent grasslands Utilisation of by-product and residue streams	(L) Areas & sustainable grazing densities (L) Product availability & feeding rates	**Lower bound:** between 1/3rd and 2/3rds of current ruminants
3. Culture & livelihoods	Culture – not quantifiable Livelihoods, an outcome not a target	L) Balanced territorial development	
4. Climate harm	GHG emissions	(U) Paris agreement emission reduction targets.	**Upper bound:** emission reductions required: 21% by 2030 47% by 2040 74% by 2050
5. Nutrient flows: water & air pollution	Nutrient balances (N only) Ammonia emissions	(L) Minimum dietary Nitrogen (U) None discovered (U) air pollution targets.	Net N balance reduction required of 62%
6-7. Biodiversity & land degradation	Farm land birds and insects Soil characteristics	Not defined	Not defined
8. AMR & Zoonoses	Non-therapeutic antibiotic use Disease outbreaks	Not defined	Not defined
9. Animal welfare	This does not lend itself to quantitative targets	Not defined	Not defined

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4 Options to shift livestock into a safe operating space

The conclusion to this point is that the EU livestock sector is not in a SOS. This chapter explores the main options available to bring livestock back into its safe space. The actions examined here have been classified into two broad groups, those addressing production and those addressing consumption. Given that the status quo is characterised by over-consumption of livestock products and excessive negative impacts, it is plain that all the actions to be discussed work on the bringing livestock within the upper boundaries of the SOS. This chapter focuses on the technical actions which would help reduce or eliminate the negative impacts of livestock. The policies to incentivise these actions are considered in Chapter 5. The analysis commences by looking at actions on the production side to see if such actions alone could bring livestock into the SOS. This sets a challenge to producer interests in the livestock sector that if they are to avoid the conclusion that consumption must change (fall) then they have to demonstrate convincingly that production adjustments alone can be sufficient.

For production, there is indeed a wide set of actions which can help reduce greenhouse gas emissions, nutrient leakage and waste, the negative impacts of livestock on other aspects of the environment and on human health and animal welfare. To achieve these ends will require the best balance of livestock types and production systems, operated at the highest achievable level of resource efficiency, and at densities which can be comfortably accommodated to respect water and air quality requirements.

Potential changes in consumption are considered in three steps, starting with the least radical. The first is whether there is scope to rebalance consumption between livestock species and products to reduce unwanted impacts. The second kind of consumption adjustment is to substitute insect, novel and synthetic protein in place of conventional livestock products. The third line of action is to encourage populations consuming above recommended protein intake levels to reduce their total protein consumption, and to substitute plant-based protein for animal products. These actions can be viewed as reducing the lower boundary of the SOS. The discussion reviews evidence on the nature and scope for these actions. The policy actions to bring about such change are dealt with in the following chapter. It is recognised at the outset that many of these actions on the consumption side require adaptation of behaviour which will require substantial change in societal preferences if they are to come about. This is a long-term project.

4.1. Adjusting livestock production: improving the resource efficiency, environmental performance, health and welfare of EU livestock production

Whatever level of EU livestock production, now and in the future, it is essential that its resource efficiency is improved, the leakages into the environment are reduced, the health status and welfare of farmed animals is increased and the use of antibiotics minimised. It is generally accepted that healthy animals kept under good conditions of animal welfare are also more productive; sick or mistreated animals do not perform well. Put another way, improving the health status of animals will generally also improve their resource efficiency. Unfortunately, the same cannot always be said for welfare improvements: for example, free range poultry systems generally have less efficient feed conversion and higher nutrient losses.

None of these are new ambitions. They have all received considerable attention for many years and substantial improvements in resource efficiency in the livestock sector have been made in the EU in the past decades. These have focussed on optimising breeding, feeding and maintaining healthy animals to produce more meat, dairy and eggs per unit of livestock, and per unit of the inputs into the system. The efficiency of any system is generally measured as a ratio of outputs to inputs. It can therefore be achieved by reducing the inputs required for a certain quantity of output or increasing the output from a given quantity of inputs. This means that the intensity of output to one or another input rises. It is unfortunate and confusing that that the very word 'intensification' has become associated in the minds of many and in common parlance as meaning an automatic worsening of some undesirable or negative impact of the activity. Yet improvement in resource efficiency will always be accompanied by an increase in the ratio, i.e. intensity, of some output to some input. This can be kilograms of live weight gain or milk production per kg of feed. It is not axiomatic that this is inevitably and always accompanied by some undesirable impact. As the benefits of research are embodied into the genotypes, animal feed, housing, plant and machinery, the knowledge intensity of production increases. The relevant resources that can be used more efficiently are the land, nutrients, energy, water, and of course labour, capital and its embodied knowledge in multiple forms – in genotypes, in feeds and equipment.

This section focuses on reducing livestock's GHG emissions and nutrient leakage to the environment. These are the two larger impacts identified in the previous chapter, more work is needed to include biodiversity and land degradation into this analysis. It is taken as read that any gains in resource efficiency should not compromise animal health and welfare. On the contrary, it is possible, and maybe even likely, that more stringent animal welfare standards may limit certain technical options to increase resource efficiency.

Measures to mitigate climate change and nutrient use efficiency are classified into two main lines of action: improving feed conversion and better manure management (Table 4). In addition to these two, housing conditions play a very important role in ensuring high livestock productivity. Heat stress is known to cause large economic losses (around 2 billion US dollars per year) in the cattle sector in the United States, and high yielding animals are particularly sensitive to changes in temperature (Rojas-Downing et al., 2017). At the same time, cooling, which whilst costly, can have a beneficial effect both on animal productivity and emissions of GHG and nitrogen. For example, keeping the slurry below slatted floors around 10°C is a strategy that reduces both methane and ammonia emissions (Petersen et al., 2013). These considerations will become more important if climate change is not addressed.

Table 4. Changes in feed and manure management that can reduce GHG emissions and nutrient loads into the environment

Changes in feed	Changes in manure management
Improving feed conversion *(e.g. feed composition, livestock breeding)* Reducing GHG emissions of feed production *(e.g.reducing fertiliser input, substituting feeds with lower GHG emissions)* Reducing enteric fermentation *(e.g. mixed diets for ruminants, use of additives)*	Better manure storage, handling and incorporation *(e.g. direct injection of liquid manure)* Anaerobic digestion to treat manure Changes in the density and concentration of livestock production

4.1.1. Mitigating greenhouse gas emissions

Many farm management practices have been identified which have the capability of reducing direct and indirect emissions from ruminants and monogastrics. For non-CO_2 emissions, the IPCC indicates that mitigation opportunities can come from changes in manure management and changes in feeding practices (Smith et al., 2014). To reduce CO_2 emissions from soils the emphasis is placed on keeping permanent pastures, conservation agriculture, crop rotations and cover crops. Measures at the farm level also include those related to energy consumption (European Parliament et al., 2013). The focus here is on actions related to livestock directly.

Globally, most of the focus of livestock research on the mitigation of GHG emissions has been centred on ruminants (Rojas-Downing et al., 2017). In the EU, more than 60% of agriculture's total livestock GHG emissions originate from cattle, and of that, enteric fermentation is the single largest emitter of methane in the EU (51% total methane emissions). Changes in feed and development of additives which change the processes in the rumen will play an important role in mitigating these. In addition, action has to be taken on cattle manure management and in dealing with pig slurry. GHG emissions from manure can be high in some MS. In Denmark, up to 40% of CH_4 emissions and 20% of total N_2O emissions are related to manure (Sommer et al., 2000).

Changes in feed. GHG emissions can be tackled through feed using three main strategies. The first is to improve the feed conversion ratio. This can be achieved by optimising feed through changes in its composition or changes in the animals themselves through breeding for feed efficiency. An optimal protein content and amino-acid balance will contribute to reducing livestock's N_2O emissions, since any excess nitrogen is excreted in manure and partially emitted as N_2O (Misselbrook et al., 1998). The second strategy is to reduce the GHG emissions arising from feed production itself. There are two main issues to consider here. One is the amount of fertilizer input used to produce feed, and the other is the possibility to choose between feed products with lower GHG emission footprints. Insects have been suggested as a potential substitute for vegetable protein, but LCA are needed to assess their potential contribution and the industry is still at its infancy. The third way of reducing GHG emissions is by providing ruminants with feed that results in less enteric fermentation in the rumen and thus lower methane emissions. This can be achieved by changing the composition of ruminant diets from one that is forage based to one with a mixed diet rich in non-structural carbohydrates[106] and through the use of additives that inhibit the formation of methane in the rumen. The microbial genomics of the rumen are not well understood and require further research before a 'zero methane cow'[107] becomes a reality[108]. Promising additives include those based on seaweed and garlic (Kinley et al., 2016; Patra, 2012), but many other substrates are being tested. However, there are drawbacks to their use such as a decrease in productivity and the fact that they may be difficult to administer to livestock which are mostly grazing. Their affordability and the ability to upscale their production are also issues must be closely examined, and their impacts on milk quality, and animal health[109]. It is also important to ensure that a reduction in one gas (e.g. methane) does not increase emissions of another (nitrous oxide). There is evidence that adding lipids in cattle feed has been shown to do exactly this (Caro et al., 2016).

Changes in manure management. GHG emissions can also be reduced by improving the storage and handling of manure, by more efficient manure incorporation in fields and by using anaerobic digestion to process manure. Because the GHG emissions take place at all stages of manure management, action must be taken simultaneously at each level. For example, in the Netherlands, 30% of indirect N_2O emissions from agriculture derive from manure (Velthof et al., 1992). GHG emissions can generally be reduced by several manure treatments including separating manure, covering it during storage and aerating or composting it. However, there are complex processes at work and, depending on the precise circumstances, these practices do not always reduce overall emissions. Anaerobic digestion is regarded as a positive contribution to reducing GHG emissions and is increasingly being taken up in some EU Member States. Animal manure (and sometimes human solid waste) usually combined with other, more energy-intensive substrates such as food waste or maize, can undergo controlled digestion by bacterial action in an oxygen-deprived, i.e. anaerobic, environment in large containers. The products of such digestion are biogases CO_2 and CH_4 and a digestate which is a useful source of nitrogen, phosphorus and potassium for crops and carbon for soils. The composition of the digestate will depend on the feedstock, and before it is returned to land there are issues which have to be considered such as smells or the presence of pathogens and pharmaceutical products. The methane produced by

Box 1. An ecological framework depicting the multiple influences on what people eat (Story et al. 2008).

- **Macro-level environments** (sectors)

Societal and cultural norms and values, food and beverage industry, food marketing and media, food and agricultural policies, economic systems, food production and distribution systems, government and political structures and policies, food assistance programs, health care systems, land use and transportation.

Additional influences: practices, policy actions and regulations.

- **Physical environments** (settings)

Home, work sites, school, after school, child care, neighbourhood and communities, restaurants and fast food outlets, supermarkets, convenience and corner stores.

Additional influences: access, availability, barriers, opportunities.

- **Social environment** (networks)

Family, friends, peers.

Additional influences: role modelling, social support, social norms.

- **Individual factors** (personal)

Cognitions, skills and behaviours, lifestyle, biological factors, demographics.

Additional influences: outcome expectations, motivations, self-efficacy, behavioural capability.

106 Which unfortunately runs counter to the idea of producing ruminants on areas not fit for food crop production.
107 See Animal Change FP7 project
108 There may be potential to adjust the genetics of the microbes themselves to foster the competitive dominance of the non-methanogens.
109 Animal change project report

the process can be burned to generate heat and power. Digested manure produces much lower GHG emissions than untreated slurry, but CH_4 emissions can occur during the cooling phase of the digestate if not collected (Sommer et al., 2000). Slurry can be treated with additives to reduce CH_4 emissions, and among these, acidification has the potential to reduce up to 90% of CH_4 emissions from pig and cattle slurry if applied before storage (Petersen et al., 2013). This brief review is enough to indicate how a wider view of the issues can help stimulate solutions by seeing the connections and symbiosis between agriculture, energy, transport and industrial processing.

4.1.2. Reducing nutrient loads into the environment

Progress on improving nutrient use efficiency has been uneven across the regions of the EU. Since agriculture is responsible for 80% of the reactive nitrogen emissions into the environment and the large majority of this comes from the livestock sector (Westhoek et al., 2015), there is a large scope for improvement. Two of the key measures to make a more efficient use of nutrients are the same as for controlling GHG emissions, namely optimised nutrient content of feed, and changes in the way manure is stored and spread. In addition to these two, agro-ecological systems propose a better integration of cropping and livestock systems, growing crops with legumes and enhancing grassland diversity as measures to reduce nutrient loads into the environment (Dumont et al., 2013; EIP Agri, 2017). A different approach, although with a similar objective, is that of the local cooperation between neighbouring specialised farms which can also re-connect crop and livestock farming. It is also important to consider that whilst climate harm caused by GHG emissions is a global issue and not location specific, the problem of excess nutrients into the environment has a strong local/regional focus. A key issue is the livestock density of certain regions which shows up clearly in the maps of nutrient surplus for the EU (see Figure 6). In the regions with highest N surplus a third category of action is to reduce the density and concentration of livestock production.

Changes in feed. Livestock production is inherently inefficient; a large percentage of N and P intake are excreted via manure. Between 60-70% of ingested N in fattening pigs and laying hens will be excreted, and for cattle it can be as much as 90% (Peyraud et al., 2012). Two mechanisms through which to reduce nutrient excretion by changing feed are to change diet and feeding practices. Changes in livestock diets will affect the quality and nutrient composition of manure. The objectives sought are to reduce the total excreted nitrogen, but also to reduce nitrogen emissions by increasing the proportion of nitrogen excreted as solid manure rather than urea (Misselbrook et al., 2005). Such changes in feed often imply changing the concentration and form of crude protein, or increasing feed digestibility, through processing or use of enzymes, which reduces the need of nutrient oversupply. An example of changes in feeding practices is the adjustment of feed to animal requirements during the different phases of growth and production, crucial to ensure high efficiency and minimum losses.

Changes in manure management. It is estimated that on average between 30% to 40% of livestock manure is deposited during grazing which offers little possibility for treatment (Petersen et al., 2013). For the remainder, there are large variations between MS in the percentage that is treated with an EU average of 8% but up to 35% in Italy and Greece (Foged et al., 2011; Petersen et al., 2013). Most of the manure produced in the EU is in the form of slurry, while solid manure represents 20%-30% of all manure management systems (Oenema et al., 2007). A simple action such as direct injection of liquid manure in agricultural soils can reduce ammonia emissions substantially[110]. As far as air pollution is concerned, this is mostly a problem of the largest livestock units. It is estimated that 80% of ammonia emissions in the EU originate on 5% of the farms (livestock farms with more than 50 LSU). The use of ammonia volatilisation inhibitors and acidification may be an option to reduce emissions at the field level, however their environmental impacts require careful evaluation. Placing covers on liquid manure can reduce NH_3 emissions at the farm level (Petersen et al., 2013). However, the nitrogen cycle in the soil is highly complex and dependent on the many variable factors at work, the same actions do not have the same effects in all circumstances. Reducing NH_3 emissions by changing the way manure is incorporated into soil can in some conditions lead to higher N_2O emissions (Vallejo et al., 2006; Velthof et al., 2010). In the Netherlands, measures to reduce NH_3 applied in the 1990s resulted in increased N_2O emissions,

110 Manure injection loses 7 times less nitrogen than manure spreading (EEB, 2016)

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due to higher N entering the soils (Velthof et al., 2010). The Nitrates and National Emission Ceilings Directives, after many years, are having some desired impacts of reducing nutrient loads into the environment but pollution hotspots remain and will require stronger action[111]. Flanders cut its ammonia emissions by half by establishing strict limits to manure application, making the spreading periods shorter and obliging farmers to take steps to incorporate manure in the soil within 2 hours of spreading, unless injected (EEB, 2016). The nitrate regulation itself is not without difficulties, th

Changing the density and concentration of livestock production

The impact of livestock systems on nutrient cycles becomes most apparent in areas with high livestock density. The geographical specialisation of livestock production poses a nutrient management challenge for large livestock farms that have very little or no land. These could be poultry, pig or feedlot cattle producers. There is a corresponding challenge for specialist crop feed producers that do not have nearby livestock production and thus manure and therefore which import large quantities of nutrient in the form of mineral fertiliser. A proposed solution is to reduce the density of livestock farming and its geographical concentration and create more mixed regions and even mixed farms. The loss of connection between livestock and arable land is exemplified by looking at the relationship between non-CO_2 emissions and agricultural area in a Member State or Region. Eurostat[112] shows that MS such as the Netherlands, Belgium or Luxembourg have the highest CH_4 and N_2O (both strongly associated with livestock) emissions per hectare of agricultural land. If this is disaggregated to NUTS 2 regions, this would show the regions of larger Members States which have similarly high rates of emissions too.

Although a geographical redistribution of livestock might in principle help to reduce the damage caused by surplus nutrient flows to water and atmosphere, more research is needed to explore the opportunities and costs of such a measure. Specialisation, scaling-up and concentration of livestock production, has been driven by strong pressure for agriculture to be market oriented and competitive and focus on cost reduction. It has been enabled by the technical developments in breeding, nutrition and animal housing and management. And for many years these developments were assisted by the commodity based support systems under the EU's Common Agricultural Policy. However, these developments have also resulted in the large externalities of water, air and atmospheric pollution.

Whether this development to large-scale concentrated production can be reversed without raising costs is not clear. The concept of 'sustainable extensification' has been proposed (van Grinsven et al., 2015) – as opposed to sustainable intensification – to reduce livestock's externalities (such as local biodiversity and environmental pollution). How to bring this about whilst maintaining profitability is a significant challenge. Dealing with this market failure usually implies some collective action – this is discussed in the following chapter. The market alone will not generally bring about the desired outcome. However, in some cases reducing livestock numbers could, locally, result in both environmental and economic benefits. An example in the Netherlands shows that low input dairy farms based on extensive grazing produce 30-40% less milk per cow but cows live longer with lower replacement costs. Similarly, pig farms allowing for increased space for pigs ('improved animal welfare') are on the rise in the country and although they represent an increased cost for farmers, consumers are showing a willingness to pay up to a 10% price premium for these standards (van Grinsven et al., 2015)[113]. The extent to which such examples can be generalised with an enduring price premium for higher environmental quality is not clear.

How plausible is it that improving nutrient use efficiency and de-concentration of production could enable the sector to move back within its SOS? There is ample evidence from farm accountancy data, and from Poore and Nemacek (2018) to show that there is a wide range in efficiency of nutrient use in feed crop production, in animal nutrition and in manure management. This indicates scope to improve efficiency by reducing the gap between the best and lowest performing farms. But, bearing in mind that improving nutrient use efficiency is in the direct economic interests of the farmer, and the considerable efforts have been undertaken to benchmark and explain the scope for improving performance, it is inconceivable that the whole gap between current NNB and the boundary could be closed by efficiency gains alone.

De-concentrating livestock production, by reducing the scale of operation and relocating some to cropping areas devoid of livestock, are even more of a challenge. Reducing production unit size and increasing their spatial separation may offer social welfare gains but may involve higher unit costs to the operator. Dairy, pigs and to some extent, poultry production have found significant economies of scale and agglomeration. This is what has brought about their concentration in the first place. This has involved considerable investment on farm and up-stream in feed compounding and other inputs, and down-stream in abattoirs and meat and milk processing.

111 https://ec.europa.eu/info/news/less-water-pollution-agriculture-worrying-hotspots-remain-and-need-stronger-action-2018-may-04_en

112 http://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_greenhouse_gas_emissions (Fig. 10)

113 Evidently the market share for improved welfare pigmeat is now 71% in the Netherlands illustrating that when the retailers and producers work together, eventually the messaging on these issues can bring about changes in consumer preferences.

It will take strong regulation and incentives to overcome these economic pressures. The welfare impacts are also complicated if de-concentration means increasing transportation distances for animals to slaughter, given the ongoing decrease in networks of small local abattoirs, mostly due to strict regulations and low profitability (Kennard and Young, 2018).

4.1.3. Alternative feed sources to reduce livestock´s impacts (and protein dependency)

As a significant fraction of the environmental impact of livestock production is associated with the large fraction of crop production devoted to animal feed, looking for less polluting feed substitutes is another strategy to bring livestock into its SOS. Although economists see nothing untoward in the idea of importing protein from places in the world which have a strong natural advantage in their production[114], there is clearly a political pressure in the EU to reduce dependency on imports of protein feed[115]. There is already in place a policy of increasing EU production of soya and legumes under the 'European strategy for the promotion of protein crops'. The use of insects and algae in animal feed and feeding pigs with swill and other food waste are under investigation as potential alternative sources of animal feed to replace domestic and imported crops. Another scheme is a green pig project: pea and faba bean to replace soya in pig feed (Houdijk et al., 2013; Smith et al., 2013).

Insect use in animal feed. Feeding insects to livestock is a promising opportunity but two challenges which remain to be addressed before it becomes a large-scale reality are: regulatory approval and the economically successful up-scaling of production. There is considerable private sector interest in innovation in this idea[116]. The European Commission is also supporting research into the use of protein feed from insects to provide sustainable high-value animal protein in the context of the Circular Economy package[117] and its Research Framework Programmes[118]. Four insect categories are considered as offering the most potential for livestock feed: houseflies, mealworms, crickets and silkworms. Insects have a high protein and lipid content, are palatable to livestock and the digestibility of their protein is high (Makkar et al., 2014). This makes them good substitutes for soya feed. Although the use of animal derived protein in feed is prohibited[119], since June 2017[120] processed animal proteins and fats can be used as feed in aquaculture, provided a series of conditions are observed such as feeding insects only with 'feed grade materials'. For pigs and poultry legislative barriers remain to allow the use of processed animal proteins. There is no harmonised authorisation across the EU and some MS are allowing the use of insects as animal feed (and human food). A risk profile of insect use in feed and food by the EFSA Scientific Committee (2015) concluded that there are still several uncertainties about the potential hazards from the consumption of insects by humans and livestock including the feedstocks, the presence of hazardous microbials and chemicals, disease spread or even allergic reactions. There is some way to go before the scale of the contribution of insects can be assessed.

There could be environmental advantages of substituting insect protein for animal feed. Insect production requires considerably less land and water compared to feed crop production, GHG emissions are lower, feed conversion efficiencies of insects are high and they're able to transform low value products into high quality food (van Huis and Oonincx, 2017). Regarding this last point, insect efficiency becomes the highest when fed with waste, provided food safety issues do not arise. Potential substrates are chicken and cattle manure, beet pulp, dried distillers' grains and municipal organic waste (Smetana et al., 2016). However, insect feed in the EU is for now limited to animal by-products allowed for feeding other farm animals to guarantee a safe food-chain. Because the development of large scale insect production has not yet materialised

114 The standard argument for the gain from international trade cannot and should not ignore externalities in production. This issue is considered in Chapter 5 below.
115 Currently more than 70% of the EU's protein rich feed is imported from abroad (Bouxin 2017).
116 https://www.reuters.com/article/us-usa-protein-bugs-insight/insect-farms-gear-up-to-feed-soaring-global-protein-demand-idUSKBN1HK1GC
117 http://ec.europa.eu/environment/circular-economy/index_en.htm
118 https://ec.europa.eu/programmes/horizon2020/

119 Regulation (EC) No 999/2001 of the European Parliament and of the Council of 22 May 2001 laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies
120 Commission Regulation (EU) 2017/893 of 24 May 2017 (limited to seven insect species)

issues of their containment (to prevent escape), their vulnerability at scale to disease and pathogens, and the appropriate way to consider their welfare have yet to receive full consideration and debate.

Algal protein in feed. A paper by Walsh et al. (2015) suggested that "*micro algae cultivation has the potential to generate quantities of biomass large enough to meet growing demand while simultaneously pursuing forest conservation policies and avoiding food insecurity*". There is a wide range of algae, many with high productivity and speed of growth compared to agricultural systems. They can produce a wide variety of plant protein, carbohydrate and lipids in terms of their nutritional value and digestibility (Becker, 2007). Their palatability and effectiveness has been investigated for poultry, pigs, and ruminants (Becker, 2003). Algal systems can be constructed on degraded or otherwise unproductive land using brackish-, sea-, or waste-water, all of which are unsuitable for conventional feedstocks. The potential of large scale alga culture seems enormous. There is much to learn about the culture process itself, which species and technology, could be suitable in Europe and their competitiveness with other regions. There are equally large questions surrounding the extraction and processing of the protein and feeding to animals and even to humans directly (Bleakley and Hayes, 2017). If this potential is realized it could have profound impacts on land use, the environment and trade.

Feeding swill to pigs. There are proposals to look again at the practice of feeding swill (food waste) to pigs and poultry to find alternative diets to lower the environmental impact of intensive animal production and the main source of their GHG emissions. Pigs consume 41% of soya meal in the EU, therefore, replacing part of the protein feed by food waste could reduce the EU's soya meal needs. A study by the University of Cambridge (zu Ermgassen et al., 2016) showed that feeding pigs with treated food waste (swill) could reduce by 21.5% the land currently used to produce their feed. Feeding swill would also reduce farmer's costs. Feed represents between more than half of the production costs for pig farmers. A successful example is the case of Japan. Japan is already recycling waste to pig feed (35% of its waste) and labels the pig products as eco-friendly. This is however a sensitive issue because of the experience with the late 1980s outbreak of BSE in cattle in the UK. The UK inquiry into the disease concluded that it had been caused by the feeding of young cattle on meat and bone meal (MBM) which had been contaminated by sheep MBM itself contaminated with scrapie (an endemic disease in sheep related to BSE). The result is an understandably cautious approach to feeding food waste materials to farm animals. Ensuring regulatory compliance in an industry dealing with heterogeneous food waste material in a continuous biological process is intrinsically challenging. Yet equally, given the scale of Europe's food waste challenge, and the impetus to activate the EU's Circular Economy Action Plan, there are powerful arguments to ensure the maximum recovery and utilization of the nutrients in food waste. The most recent step in is the publication of the European Commission's Guidelines for the feed use of food no longer intended for human consumption (European Commission, 2018).

4.1.4. Scope and extent of these measures

Each of the options discussed above has potential to reduce some GHG emissions and nutrient losses into the environment associated with livestock production. The drive to improve resource efficiency and to be aware of the damage caused by leakage to soil, water and atmosphere are long term efforts which have been underway for several decades. Europe's Nitrate and Water Framework Directives together with the Common Agricultural Policy have incentivised improvement. There are indicators showing progress for example more efficient fertiliser use, reduction in GHG emissions[121] and nutrient loss, and improvement in river water quality. However, the evidence referred to in Chapter 2 and the distance from achieving environmental objectives indicated in Chapter 3 suggest there is still a long way to go to bring the sector into its SOS.

Broadly two kinds of actions on the production side have been reviewed. First, those requiring changes at farm level in the management of livestock, albeit using technologies and knowledge provided by other partners in the livestock supply chain e.g. for breeding and animal health. There is wide variability from the top to bottom quartile of producers in the technical, economic and environmental performance of individual farms. Indeed, it is the very existence of this variability which provides the scope for improvement. This has been known for decades, yet it is a slow process through benchmarking, information provision, training, upskilling, and other means to narrow the economic and environmental performance gap between farms. Second, are actions upstream of farming essentially in the feed sector which, at least initially, require large scale investments. These can be to identify and provide feed additives for methane inhibition, or in novel feed manufacture through insects, algae or novel methods of synthetic protein culture. The up-scaling of completely new sources of protein for animal feed has great promise, but large-scale application remains untested. It will take time to assess the real contribution such approaches can make, and the economic and environmental challenges which must be overcome to make it work. These opportunities again indicate that holistic food-system approaches which see the connections between rural and

121 The significant drop in GHG emissions from 1990 to 2010 was mostly due to reducing cattle numbers partly brought about by changes in agricultural policy, recent signs are that emissions are now increasing.

urban developments can help both.

The FAO stresses that productivity improvements in the sector, restoration of degraded grasslands and better integration of livestock in the circular bioeconomy could contribute to tackle climate change globally (FAO, 2017)[122]. However, the largest potential for productivity improvement and reduction of the associated GHG emissions globally is located outside of the EU, where productivity is still low. It is estimated that a maximum of 20% GHG emission reduction could be achieved in the EU by 2025 due to the already high productivity of the sector that leaves relatively little room for mitigation gains (AnimalChange, 2015). The same source indicates that in the longer run the reduction could be larger – up to 50% – but the measures to be taken to achieve this would go beyond direct technical improvements encompassing also geographical relocations of livestock and introduction of legumes in grasslands.

The implementation of technological improvements will be limited by their cost-effectiveness[123]. Also, as the EU becomes more efficient, successive rounds of reductions in emissions may turn to be more difficult and less cost-effective. Above all, however, implementation will depend on the will of the individual MS[124] and, ultimately, on the will of farmers and the opportunities given to them.

Taken together, these considerations lead to the judgement that working on production efficiency whilst absolutely necessary, will not be sufficient to take EU livestock back into its safe operating space. Action will also be needed on the consumption of livestock products, this is examined in the following section.

4.2. Options for adjusting consumption of livestock products

Western liberal democracies are generally reluctant to tell citizens what is good for them and what they should consume. The 'customer knows best', 'consumer sovereignty' and avoidance of 'the nanny state' are the catch phrases of this view. However, there is a growing number of examples where self-harm, harm to bystanders and more general negative spill overs to other citizens from the consumption behaviour of individuals leads to collective action to modify consumption. Obvious examples are tobacco, alcohol and various drugs. Taxes, restrictions on sales or consumption in public, coupled with strong public awareness campaigns and education, are some of the tools used to modify behaviour. There have been attempts to introduce such measures for fats, and more recently for sugar. No such measures have been attempted yet aimed at general livestock products or meats. This might have to change.

The two powerful arguments for this are first that it is concluded that EU livestock are not in, nor very close to, their safe operating space, and that with the best will in the world, operating on improving the efficiency of livestock production alone will not be sufficient to bring the sector into the SOS. Second, a high and rising proportion of Europeans are over-consuming animal protein. This is harmful to their individual health and it is costly to our societies to fund the health care costs it precipitates[125]. Furthermore, it is extremely wasteful of the world's scarce agricultural resources (land, water, fertile soils) to produce crops to feed to animals to produce protein which is then simply burned for energy, especially because this system is all too often accompanied by severe damage to climate, water quality and availability, biodiversity and animal welfare. Ways of modifying livestock consumption have therefore to be considered.

Three changes in consumption are considered involving successively greater scales of adjustment: (i) changing the species balance of animal protein consumption, (ii) substituting conventional livestock products with alternative animal-based protein in human diets, and (iii) reducing total protein intake and substituting animal-based protein with plant-based protein.

4.2.1. Changing the species balance of animal protein consumption

A mechanism to reduce the negative impacts of livestock on the environment and human health without having to change overall levels of animal protein consumption is to rebalance current consumption to substitute animal proteins that are highly resource intensive or leaky with products that are more resource efficient and less leaky (Bouwman et al., 2013; de Vries and de Boer, 2010). Shifting from beef, sheep and goat meat to pork, chicken and fish would be generally expected to reduce GHG emissions[126]. Life Cycle Analysis (LCA) studies indicate that, on average, a kilogram of beef meat produced in the EU emits 6 times more CO_{2e} than a kilo of pigmeat and 14

122 They specifically mention: "increasing the share of by-products or waste that humans cannot eat in the livestock feed ration or by recycling and recovering nutrients and energy from animal waste (e.g. biogas)"
123 https://ec.europa.eu/eip/agriculture/en/focus-groups/reducing-emissions-cattle-farming
124 See post by Alan Matthews on the mitigation potential in EU agriculture: http://capreform.eu/mitigation-potential-in-eu-agriculture/

125 The scale of the societal costs of obesity and related ill-health is eye-opening, it has been estimated that it is about five-times the economic benefit of agricultural output. Not all of this is due to livestock products. The potential public finance savings from better diet could easily help fund a different approach to food production.
126 This is the case when averages are used, but emissions can vary largely between the same species depending on the systems in which they are raised (especially the extent of concentrate feed versus forage or by-products).

Table 5. Qualitative impacts of displacing a unit of one livestock product with another product of equivalent nutritional value

	GHG emissions	Nutrient Leakage	Water & Air Quality	Biodiversity	Zoonoses & AMR	Animal Welfare
Beef to poultry						
Beef to dairy						
Poultry to beef						
Poultry to dairy						
Dairy to beef						
Dairy to poultry						

(e.g. beef to poultry reduces consumption of beef and increases that of poultry. Red colour indicates a worsening of the situation while dark green indicates improvement. Lighter tones of orange indicate likely worsening and those of green likely improving).

times more than a kilo of poultry meat (Lesschen et al., 2011). Röos et al. (2016) calculate that a shift from beef to poultry meat would therefore substantially reduce GHG emissions, perhaps as much as 50%. The situation is more complex for dairy. EU citizens consume large amounts of dairy products and although there are apparently low CO_2 emissions when expressed per litre of milk, total GHG emissions from the dairy sector are slightly above those from beef and seven times higher than total emissions from poultry meat consumption[127]. Also, a large percentage of the milk is consumed in the form of cheese, butter, cream and yogurt, with GHG emissions per kilogram of product (once the water is removed) much higher than those of milk itself. Production of a kilo of cheese or butter is associated with more CO_2 equivalent emissions than a kilo of poultry meat and, for some systems, more than a kilo of pigmeat (Flysjö et al., 2014). Thus, reducing the two meats with highest consumption in the EU, pig meat and poultry meat by substituting them with dairy products will not bring about a reduction in GHG emissions.

While there are benefits from a climate perspective, negative impacts can arise from substituting beef with poultry. Much poultry production in the EU comes from very large production units which raises a question of their relative welfare status. This is a particularly difficult matter to assess. It should not be assumed that all large and intensive poultry units have the same or necessarily low levels of animal welfare any more than all extensive beef systems offer identical high welfare standards. Furthermore, there is no scientifically measurable indicator of welfare at either the individual animal level or herd/flock level; neither is it clear how to aggregate animal discomfort and compare it between species and systems. This contrasts strongly with the measurement of GHG emissions[128]. A common presumption might be that a shift from poultry raised in an intensive large-scale unit to grass-based beef would be associated with raised animal welfare. However, such assumptions should be scientifically validated before public policy is engaged to encourage such behavioural change. In addition, the impacts on other factors such as disease spread, increased antibiotic use and resistance and increased soya use also have to be considered when shifting to poultry or pigmeat consumption in detriment of beef (Gelder et al., 2008)[129].

Grass-based beef may rely little on grains and concentrated sources of plant protein such as soya, however,

127 Average annual EU consumption is 214 kg of milk, 22.6 kg of beef and 24.1 kg of poultry meat, resulting in CO_2 equivalent emissions of: 278 kg for milk, 244 kg for beef meat and 1.6 kg for poultry meat (using data from Chapter 3 and from Lesschen et al., 2011)

128 Whilst the unit of measurement and the methodologies for estimating emissions are internationally agreed, the emission factors for agriculture have high standard errors and there is very little field measurement involved. The apparent precision of estimates is probably misleading.

129 Gelder et al. calculated the amount of soya used per unit of meat, being 232 g per kg for beef and veal, 648 for pork and 967 g per kg for poultry.

poultry are much more efficient converters of feed into product. The impact of different production systems also must be considered. In the case of beef, the total impact will depend on the origin of the calves, their feed and the production method. There are also different ways of accounting for impacts, for example how to allocate GHG emissions between beef and dairy in dual production systems (de Vries and de Boer, 2010). In a review of LCA studies, de Vries et al. (2015) concluded that beef systems where calves originate from dairy herds have a lower GHG emissions, a lower acidification potential, a lower eutrophication potential and a lower land use than those based on suckler calves. The differences in these factors ranging between 13% and 76%. And despite its large contribution to GHG emissions, grass-fed beef on low intensity grasslands has a lower negative impact on soil erosion, biodiversity and nutrient leaching than beef on high productive grassland systems (de Vries et al., 2015). Organic systems are linked to higher GHG emissions per unit of product and higher eutrophication and acidification potential, although their energy use is lower (Alig et al., 2012). Pasture based systems also offer a way to convert non-human edible proteins into human edible proteins in regions where land suitability does not allow cultivation of crops for human consumption (de Vries et al., 2015), and provide milk and dairy with a better nutritional profile than those of non-grazing cattle (Daley et al., 2010), in addition to reducing fire risk in fire prone areas such as the Mediterranean. This goes some way to reduce the competition between food and feed. Additionally, since two thirds of EU beef originate from dairy herds, shifting beef consumption to pork or chicken without addressing dairy at the same time may not achieve the desired results.

Human health considerations point to targeting red meat especially in the form of processed meat according to WHO guidelines. This applies to both beef and pigmeat consumption, which is the second most popular meat in the EU (after poultry) and much of which is consumed in processed form. Replacing at least part of the current pigmeat consumption with more poultry meat might reduce disease incidence associated with intake of red and processed meat. It could on the other hand increase the risk from zoonoses and antimicrobial resistance if the expansion of poultry consumption was provided through larger and intensive systems.

This brief review should be sufficient to illustrate the complexities of judging the desirability of the substitutions of one kind of livestock product for another. Table 5 summarises six possible substitutions between three broad categories of livestock products: red meat, white meat and dairy products.

The mental experiment is to imagine the impacts of displacing 1000 tonnes of the first product with an equivalent amount of the second product which supplies the same amount of protein. The six impacts of concern shown are: GHG emissions, nutrient leakage, water and air quality, biodiversity, zoonoses and AMR, and animal welfare. The colour coding is intended to show deeper shades of orange going to red for a substitution which worsens the variable and deeper shades of green for improvement. In this table the results are qualitative judgements not the results of research investigations. There is little empirical analysis to measure such effects.

Merely constructing such a table illustrates the challenges which must be overcome if this kind of analysis can usefully inform consumer choice and policy. First is the empirical issue of defining and finding data on the six impact categories. Second is to estimate the impacts for specified substitutions. There are many different ways to produce the same product (beef, pork, chicken). The different production systems, e.g. feedlot versus entirely grass-fed beef, outdoor versus housed pigs, can be operated at many different scales and will have varying degrees of efficiency, and quite different environmental impacts (Rodríguez-Ortega et al., 2017). For instance, in Belgium extensively farmed cattle show lower resistance to antimicrobials and receive around 25% less antibiotics than their intensively kept counterparts (Catry et al., 2016). So, the impacts will be quite specific to the experimental / measurement situation. This is not unusual in judging agricultural systems, and with sufficient care, case studies and field observations could help populate a table like this. But that would only be the first step. The next step is to draw conclusions. For example, in row 1 in the table (poultry meat displacing red meat) does the expected improvement in, say, GHG emissions, nutrients, water and air quality from the substitution outweigh the deterioration in zoonoses, AMR resistance and animal welfare? There is no obvious numeraire or scale to deploy to make this judgement. No doubt individual consumers would have quite different assessment of the importance of these impacts.

4.2.2. Substituting alternative animal based protein for conventional livestock products in human diets

Two main types of alternative protein which humans could substitute for farmed meat, eggs and dairy products are considered: cultured meat and insects. It is recognised that a third broad category of animal based protein is fish and other sea food and but there are inevitable trade-offs and challenges to consider if consumption of fish and sea food were to significantly expand. There is an underlying presumption that because natural fisheries resources are under as much pressure as terrestrial resources, and because farmed fish, i.e. aquaculture, both marine and freshwater, are subject to similar concerns about their environmental and animal health and welfare impacts as for farmed livestock, there is little scope for large-scale substitution of fish for current livestock consumption.

This hypothesis deserves testing but is beyond the scope of the current project.

Large technological and regulatory advances are being made to develop cultured livestock products and to accept insect protein into the market. Many products are becoming available and no doubt public perception partly limits the pace of these developments.

Cultured meat (in vitro meat) is animal tissue produced in a laboratory from animal cells. Prof. Mark Post from Maastricht University presented the first cultured burger in 2013 and although it is still not commercialised, cultured meat is regarded as a potential substitute for ground meat (beef, pork or lamb) and chicken meat in the future. The development of cultured meat is usually explained as a response to societal concerns about the impacts of livestock on the environment and human health. It also appeals to consumers who do not want to give up animal protein and are concerned with animal welfare. The environmental benefits of cultured meat could be substantial but because the scale of their development is at its infancy these benefits are subject to large uncertainty. It is claimed that cultured meat will require almost no land, very little water and the associated GHG emissions are one third those of poultry (Tuomisto and Roy, 2012). It could potentially reduce significantly the air and water pollution of animal production and the management of manure and slurry. Cultured meat also has advantages in terms of food waste. It could avoid the production of the large volumes of waste material from livestock production (bones, entrails, offal and so on) and waste in the food processing chain. Another advantage of cultured meat is the ability to control the amount of fat, nutritional value and taste of the meat substitute products.

This technology is at its infancy with great challenges to be overcome. Considerably more development and LCA assessment is necessary before these claims can be confirmed at scale and the impacts on human health and the environment. A controversial issue in the production of cultured meat is the use of serum from animal blood. While the cells feed on a medium based on carbohydrates, minerals and vitamins that provides all the nutrients they need, they also require protein as a growth factor. This protein is provided, currently at very high cost, through animal-based serums[130]. Besides increasing the cost of cultured meat, the use of serum from bovine foetuses to produce a meat that is supposed to eliminate animal suffering is controversial and researchers are looking at alternative substances that can play the same role. Further questions surround the feedstocks for large scale production, its energy consumption and the vulnerability of meat cultures to bacterial infections and thus need for antimicrobials (Mattick et al., 2015). Large investments are being made in this sector, especially in Silicon Valley, suggesting that cultured meat, at least in the form of ground meat, could soon be a reality in our supermarket shelves. Higher value cuts might prove more difficult to be produced.

Insects are another source of alternative protein under consideration. Insects as food are regulated under the EU Regulation on Novel Foods (2015/2283). Their presence in EU markets is very limited to date. The advantages of insects in comparison to livestock are similar to those for cultured meat. It has been quantified that insects have a lower footprint than chicken or even whey proteins, which they could replace when presented in powdered form (Smetana et al., 2016; van Huis and Oonincx, 2017). Consumer acceptability of insect-based foods or ingredients is a major issue, and as the risks, regulatory hurdles and marketing effort likely to be required are so much higher for human consumption than for animal feed it is

130 For more information read: https://www.wired.com/story/lab-grown-meat/

likely that any major development will first be in the latter. As in the case of insect use in animal feed, there are many issues which still need to be addressed such as the regulatory framework, challenges related to upscaling production such as their containment and the availability of consistent supplies of feedstock for the insects, there may be risks arising from disease spread or allergy reactions as well societal acceptance of insects as food.

4.2.3. Reducing total animal-based product intake

The third mechanism to reduce livestock's impacts consists in directly addressing consumption levels of meat, dairy and eggs and associate waste of these products in the EU. Over the last decade, many organisations[131] and official bodies have suggested that changes in consumption patterns are an inevitable step to reduce GHG emissions from the livestock sector and to reduce livestock's negative impacts on other aspects of the environment and on human health. Quantitative analyses of the benefits such measures would bring about are still scarce, but they are gaining attention. Such proposals for reductions in consumption implicitly or explicitly assume that production would have to be reduced equally. The implications of consumption declining faster or slower than production are important as they turn the EU into a net exporter or importer of livestock products. This issue is treated in Chapter 5.

The questions are: how much and what balance of reduction in consumption is required? Environmental and health effects are discussed in turn.

Environmental effects

Several studies have concluded that a 50% reduction in current MDE consumption in the EU would make a significant contribution to climate change mitigation and would at the same time align current intake of animal protein and fats with WHO recommended dietary guidelines (Westhoek et al., 2014). Cutting current consumption by half would reduce GHG emissions from the livestock sector by 20-40% (Behrens et al., 2017; Bellarby et al., 2013; Stehfest et al., 2009; Westhoek et al., 2014) (depending on the type of meat). The largest contributor to the reduction in emissions would be the fall in methane from cattle. Some global studies suggest an even larger reduction of consumption in the EU, given that a uniform diet across the globe, even if low in meat, should allow some countries to increase their current meat intake which is especially necessary for children in countries with very low MDE consumption levels. In such studies, a 50% reduction in global consumption of MDE translates into a 70% reduction in the EU, and the potential mitigation of GHG emissions globally could be up to two thirds of current emissions (Eating Better, 2018; Tirado et al., 2018). Other studies suggest that sticking to a 'Healthy Diet' would reduce GHG emissions by 20% and GHG mitigation costs by 54% (Stehfest et al., 2009).

Less explored has been the impact of reduced MDE consumption on the nutrient cycles or on the other negative impacts of livestock, although the European Environmental Agency (EEA, 2017a) has identified changing diets towards lower consumption of livestock products as a main lever to reduce nutrient losses, together with improvements in nutrient use efficiency in reduction of food chain waste. Westhoek et al. (2014) suggest that a 50% dietary reduction in MDE would result in 40% less reactive nitrogen emissions from agriculture, largely reducing eutrophication and acidification in aquatic environments. However, given the geographically specific nature of the impact of nutrient emissions, these benefits would be achieved by focussing adjustment in the areas with currently high levels of nutrient loads into the environment. The impact of less livestock on land use is more straightforward to calculate. In the EU, 23% less cropland area would be needed if livestock were reduced by half, while globally reducing livestock consumption would also free up large areas (23% less cropland) of land to regrow forests, produce crops, biofuels, re-wild it, or use it for human habitation (Stehfest et al., 2009; Westhoek et al., 2014).

Given that the starting position in the EU (on average) is overconsumption both of protein and of carbohydrates, intuitively, it seems reasonable to assume that the lower pressure on land, water and other resources brought about by significantly reduced livestock consumption, and a corresponding fall in EU production, would help reduce all the negative environment impacts discussed in this report. Behrens et al. (2017) suggest that simply following national recommended diets would result in significant reductions in GHG emissions, eutrophication and land use globally. However, a fall in production would of course also reduce employment in the livestock chain and could lead to significant stranded assets both on-farm but more especially upstream (animal feed and animal health sectors) and downstream (transport, slaughter and processing) of farming. It is not sufficient simply to assume these effects. Much depends on which types and systems of livestock production are reduced, and whether there is a compensating increase in crop product consumption and production. If the scaling back is in the relatively extensive livestock systems and regions, the reductions in environmental impact could be small. But the relative contribution to total milk and meat production from such regions is also small, so significant reductions in negative environmental impacts will have to come from the more intensive regions and productions systems. This deserves detailed investigation. There are quite different impacts of reducing consumption of the

131 In the EU : Netherlands, etc. In the US: Dietary Guidelines Advisory Committee (DGAC) (2015)

different livestock products so the balance of the reductions in consumption is important. Also, reduction in livestock production and associated feed production may, to some extent, be offset by expansion in crop production for direct human consumption.

It is equally easy to assume that a large change in livestock product consumption would automatically bring about comparable improvements in animal health and welfare. This too should not be assumed but analysed carefully.

Health benefits

Several definitions of 'healthy diets' and their impacts have been explored in the research literature. These diets aim at reducing GHG emissions but also obtaining human health benefits, such as reducing the incidence of cardiovascular diseases, certain types of cancer, type 2 diabetes and obesity (Tilman and Clark, 2014). The large public health cost savings associated with such diets (Springmann et al., 2016) could be a stimulus towards their implementation. However, exploring different dietary options requires accounting for the effect of different meat types and dairy on human health, including the impact of different dietary compositions on vulnerable groups (Lal et al., 2017). In general, reducing the consumption of all meats and dairy by 50% would align the intake of saturated fats with the levels recommended by the WHO (Westhoek et al., 2014), and limiting red meat intake to WHO recommended level (43g/day) would be a key factor in reducing stroke, cancer and diabetes in Western high-income countries, implying large cost savings (Springmann et al., 2016). A reduction in all meats is required to achieve this, given that a reduction in beef and dairy alone would not bring down saturated fat levels to the recommended guidelines (Westhoek et al., 2014). Estimates for the UK suggest that an 83% cut in MDE consumption would save £1.2 billion in health care costs (Scarborough et al., 2010). Indirect impacts on human health would also include lower use of antimicrobials, reduced risk of zoonoses and improved water and air quality (Westhoek et al., 2014).

4.2.4. Replacing animal-based products

If society is to reduce MDE consumption by a significant amount such as 50%, it is important to consider whether this will stimulate increased consumption of other foods, which foods, and with what effects on health and environment? It may well be that people will not eat less, they will eat differently. The products which replace livestock will determine the effective impact of reducing MDE consumption on human health and the environment. In many modelling studies scientists assume that cereals replace livestock products to an equivalent energy intake, however, this may not be necessarily the case. Also, any changes in diets in the EU will not be homogeneous throughout the MS and by demographic segments (Vieux et al., 2018).

The focus on reducing animal fat consumption in previous decades has now been called into question since efforts to make diets healthier have not yielded the hoped-for results. In diets where animal fats were replaced with carbohydrates and oils the expected benefits of eating less animal fats on human health and particularly on the incidence of cardiovascular diseases were not found (Binnie et al., 2014; Dehghan et al., 2017). Environmental benefits may also not automatically appear from reduced livestock product consumption. Some vegan and vegetarian diets with high consumption of proteins and fats could have a larger carbon footprint than omnivore diets (Rosi et al., 2017)[132], although in general the contribution to GHG emissions is larger for livestock products (Blonk Consultants, 2017). In 2009, the WWF estimated that a 50% reduction in livestock production and consumption in the UK would release up to 1.6 million hectares of land, however, 1 million hectares would be needed for additional crop production, resulting in a net release of 0.6 million hectares (Audsley et al., 2009).

Wellesley (2017) suggests three reasons why cultured meat or plant-based products in the shape of meat products are good alternatives to waiting for consumers to reduce meat consumption: 1) limited success of campaigns to raise consumer awareness on environmental impacts of meat production; 2) animal welfare and sustainability criteria are second to convenience and appeal at the moment of purchase; 3) changing the kind of meat we eat has greater potential for success, at least for now, than cutting the amount of meat we eat.

There are several possible substitutes for the reduction in animal products. Many studies assume that the reduction in animal protein will be replaced by increased consumption of cereals (Westhoek et al., 2014). However, in a society used to the idea that a complete meal includes some sort of animal protein, a surge of meat & dairy substitutes may play an important role. The main reason for their uptake is that they don´t require significant changes in the way food is prepared or presented. An example is the replacement of milk by vegetable-based drinks from cereals, legumes, nuts or even seeds. Perceived as healthier options to milk and without presence of lactose, sales of these drinks doubled in western Europe between 2010-2014 with soya drinks having more than 40% of the market share but falling now in favour of almond drinks (MI, 2018). There are also increasing choices of vegetable material sold in the shape of sausages and hamburgers, some of which are made to taste like meat but have a reduced environmental impact. These products respond to a demand from a segment in society that has mostly become concerned with the links between livestock pro-

132 0.8 kg CO_2 equivalentare associated to a pack of two avocados, more than a glass of milk, and it has detrimental effects on the environments where it's being grown.

duction and harm to animal welfare. However, there is also increasing awareness of the negative impacts of livestock products on human health and the environment. As these links become more and more explicit in the media, and this segment grows, the willingness of consumers to change their consumption patterns in favour of less intense meat diets increases (Wellesley et al., 2015). The European Commission has itself provided funds through its Research Framework Programmes for the development of these alternatives. The EU is the largest market for vegetable meat substitutes in the world, accounting for 39% of the total revenues in 2014, and consumption is expected to continue growing[133].

For consumers seeking to replace animal-based protein, pulses, algae and soya are a good source of proteins for human diets. The protein levels of algae are like those of livestock products and soya bean but they require up to seven times less production area for an equal amount of protein yield than legumes or soya. Algae are an extremely wide class of plants with an equally wide range of concentration and make-up of amino acids which can be processed into forms suitable as food ingredients or 'nutriceuticals'. At present, however, their production is limited by legal, economic and technical reasons and more research is needed to assess their digestibility and the bioavailability of its proteins (Bleakley and Hayes, 2017).

A widely consumed and well-studied meat substitute which was launched in the mid-1980s is the branded product Quorn. This is a mycoprotein based product derived in a continuous fermentation process using the fungus *Fusarium venenatum*. It is strictly not a vegan product as it uses egg white, or dairy products, to bind the material, but it is accepted as a vegetarian product. It is sold in various formats as an ingredient for consumers to prepare as they wish in their own recipes and processed into a wide and growing range of prepared food products. The evidence on the motivation of its consumers is that they are mostly concerned about health and to a lesser extent about the environment. In established markets, consumption is growing rapidly [134] and its manufacturers are exploring ways to market it in Asia and other parts of the world (Askew, 2017). Its story provides an interesting insight into the time it takes, and the technical, regulatory and marketing hurdles which must be overcome to develop novel foods.

As meat and dairy substitutes increase in popularity some concerns are raised about the adequacy of levels of iodine, serum ferritin, vitamin D, and calcium intake and the impact that a diet with reduced Vitamin D could have on the development of osteoporosis (see section 2.2.1) (Givens, 2018). There are claims and counter-claims on this subject with more research required to reach definitive conclusions.

4.3. What combination of actions is required?

The many actions identified on production and on consumption are not mutually exclusive: all have a contribution to help the sector back to its SOS. It was explained in Chapter 3 that there is no easily identifiable socially optimal level and composition of livestock because of the multiple interactive variables required to define the SOS and the fact that several of them (e.g. acceptable employment levels, and animal health and welfare) are not amenable to quantification and stem from societal choices. It is therefore no surprise that it is not possible at the current state of knowledge and analysis to identify a neat combination of actions which will bring the sector back into balance.

The first conclusion is that there is no choice but to continue efforts to promote more resource efficient production, primarily to reduce leakage. Simultaneously, efforts must be made to encourage changes in consumption patterns in the general direction of reducing overall consumption[135]. This is of particular importance at a time when adapting to climate change will already require farmers to change their practices and maybe even the scale of their activities.

The European Academies' Science Advisory Council recommends in a 2017 report (Lal et al., 2017) the importance of "assessing any disconnects between the implications of the COP21 (Paris Climate Agreement) objectives for livestock and meat consumption, and standard recommendations for consuming healthy diets" and that the potential of alternative meat sources, such as cell-cultured meat and alternative proteins, should be explored to lower the environmental impact of the livestock sector. They acknowledge that changes in the demand of livestock products must be addressed to achieve the large adjustments required to meet climate targets. They also mention that demand-side strategies will be required to address overconsumption and change dietary habits to reduce food associated GHG emissions. Similar conclusions are reached by the Lancet Countdown (Watts et al., 2017).

There are research results which have modelled various combinations of measures which can inform and guide this process. Bellarby et al. (2013) showed that a combined reduction in the consumption and production

133 https://www.globalmeatnews.com/Article/2016/02/25/Meat-substitute-market-expected-to-hit-5.2bn-by-2020

134 Rapid annual growth rates are invariably cited by proponents of specialist foods, but as they relate to extremely small base level they appear misleading.

135 These two simply stated requirements may be in opposition; improved resource efficiency may lead to lower real costs of production and lower real product prices encouraging more and not less consumption.

of livestock products together with a reduction in food waste and technological improvements could cut emissions from the livestock sector between 12% and 67%. The authors stressed the fact that keeping current livestock numbers even with more technically sophisticated systems would not achieve emission reduction targets. In their article, they also encouraged grazing on rough grazing land where possible (Bellarby et al., 2013). The study concludes that if other actions are taken simultaneously, such as a reduction in food waste and improved efficiency in the ways mentioned in the section above, the reduction in GHG emissions for the EU could reach up to 67% in the long term (Bellarby et al., 2013).

Other proposed solutions focus on reducing livestock numbers and feeding those remaining with residues and scraps. Shader et al. (2015) show that reducing meat consumption (by 71%) and feeding livestock with food waste and crop residues could be an effective strategy to reduce significantly the environmental burden of the livestock sector. These authors calculate that such a strategy could provide sufficient food – as measured by equivalent amounts of human-digestible energy and a similar protein/calorie ratio as in a reference scenario for 2050 – and it could significantly reduce environmental impacts compared to this scenario. In their most extreme case where livestock receive no otherwise human-edible concentrate feed, the impacts on GHG emissions is an 18% reduction, arable land falls 26%, N-surplus falls 46%; P-surplus falls by 40%; non-renewable energy use by 36%, pesticide use intensity falls 22%, freshwater use falls 21%, and soil erosion potential drops 12%.

Another way to approach the necessary change is to look for the combination of actions that can increase livestock´s positive contributions to society and ecosystems. These could result from a combination of lower consumption and the promotion of livestock systems that enhance livestock´s benefits. Agro-ecology provides responses to these challenges by favouring low input systems and minimising livestock´s negative outputs. Although ruminants are the focus of most of the attention on livestock´s negative impacts, they are also inevitably the main actor in agro-ecological livestock approaches due to their ability to graze. It is stressed that in such systems ruminants should feed on permanent pasture only and especially in marginal areas (Dumont et al., 2013). An important component of agro-ecological systems is resilience by giving preference to breeds adapted to local conditions, rather than opting directly for high performing ones. This is particularly important in the case of ruminants since climate change is expected to increase the annual and inter-annual variability in forage quality and its total availability (Havet et al., 2014). At the same time, it creates an additional opportunity to emphasise local produce and gives farmers the possibility to differentiate their products in the market.

Overall, the scale of contraction of production and consumption indicated in Chapter 3 may seem very high and unattainable. But contraction is far from unheard. Smaller contractions of the sector have already taken place. For instance, the 20% reduction in GHG emissions from agriculture experienced between 1990 and 2015 was driven largely by a reduction in livestock numbers (cattle and sheep)[136] and a reduction in the use of nitrogenous fertilizers. There have been periods of quite large cuts in pig numbers in the Netherlands and UK, and in sheep numbers in the UK. The reductions that are now being sought are however of a different order of magnitude and will have to be sustained. Larger efforts will need to be made specially to reduce methane emissions, since during 1990 and 2015 the reduction in methane emissions in the livestock sector was low compared to that of other sectors of the economy that have managed to reduce them by half. Increased production and expansion of the dairy sector have kept methane emissions high (Science for Environmental Policy, 2013), but lack of markets for some of the products could add additional pressure to the sector to contract. This seems a straightforward option in terms of impact reduction but a more complicated one to implement on the ground.

Global demand for livestock products has significantly increased over the last fifty years and is expected to continue doing so, but the future trajectory of this demand appears increasingly uncertain (Lal et al., 2017). Increased awareness of livestock's impacts may already be driving a change in consumption patterns. There is also a generational gap. While older generations choosing to eat less meat do so from a health point of view, younger generations are ready to eat less meat for environmental and animal welfare purposes. In France, young people already eat less beef and more poultry than older generations (Frioux et al., 2017). As incomes increase, people may also consume less meat. In the UK, the number of vegans has more than trebled over the last ten years (albeit from a very low base) and half of them are under 34 years of age (Marsh, 2016).

Change is happening. However different cultures respond to different pressures. The broad analysis presented here can orient future policies, but solutions will have to be found locally, respecting the diversity in the EU and always taking into account the environmental and socio-economic context.

136 Eurostat, 2017, 'Agri-environmental indicator -greenhouse gas emissions'

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5 How to move livestock into a safe operating space

5.1 The scale and complexity of the challenge

This study has concluded that EU livestock are not in a safe operating space. There are exceptions for some products in some countries, but for the EU, on average, consumption of livestock products is above what is recommended for good health in official nutrition advice. The resulting over-consumption of animal protein (5% excess milk and 65% excess meat on average) is extremely wasteful and associated with significant environmental harm. Ruminant numbers are between one-third and two-thirds above the levels necessary to occupy and sustainably graze the permanent pastures of the EU. Greenhouse gas emissions from livestock, from the management of their wastes, and from the production of their feed, are a significant share of total EU emissions. This share is expected to grow because the likely reduction in emissions by improvements in feed efficiency and manure management are judged to be insufficient to reduce emissions by the magnitudes agreed for the whole economy. In addition, the nutrient flows, principally nitrogen and phosphorus, a large part of which is directly or indirectly associated with livestock production are creating unacceptable water and air pollution and damage to health.

The key general actions to deal with these challenges are to reduce wasteful over-consumption of animal products, switch towards plant-based protein and encourage substitution of new and novel protein for animal protein. As this happens livestock numbers will probably fall, the resource efficiency of remaining livestock improved and leakages and waste reduced. The question is how to motivate these actions?

The challenge is immense because the scale of change in livestock product consumption and production necessary to get the EU sector into a safe operating space is large, and it will require action from a large proportion of consumers and all participants in the livestock food chain. To motivate this demands a high-level strategic systems-view to be taken by the EU and Member State Governments which embraces food, farming, nutrition, health, environment, trade and development. The policies for each of these areas must strive towards common goals within a common food system policy. Without this there is a danger of continued policy incoherence between these vital elements.

The task is most definitely not the elimination of livestock, but a substantial contraction of its harmful environmental and health effects. It is suggested that this cannot be achieved without reduction in animal numbers. Reductions of impacts of 40% to 70% are indicated in this and numerous other studies. Such a scale of adjustment should be viewed as a transition process to be accomplished over the next three decades. This adjustment is immense yet achievable. The justification for undertaking it is that the societal benefits outweigh the costs . It will inevitably involve unwelcome change for some in making the transition, but it will stimulate innovation and new economic activity, and it will pave the way to long term gains in human health and wellbeing as the livestock sector moves onto a sustainable basis by avoiding the current threat of irreparable and irreversible damage to climate, waters and ecosystems.

The political system must be an active player in two principal ways. First it must alert citizens to the need for change and spur the changes into effect, second it must act on the policy incoherence which runs counter to required action in the EU. Key examples of such incoherence are the implicit subsidies to meat, dairy and eggs in the VAT system, current supports under the Common Agricultural Policy which are not related to market failures and public good purchase, and the high level of protection of livestock products from world markets.

The policy actions required are discussed in more detail in sections 5.2 and 5.3 respectively for consumers and producers. Actions to bring about consumption change are deliberately considered first. As they take effect and consumers choose to change the amount and the source of protein they consume, farmers and the food industry will then adjust to these evolving demands. They will have no choice in this.

Change will not be brought about by a frontal assault on the livestock production sector. This is a large and complex economic sector. At the head of the food chain are the input suppliers – genetics, feeds, health products, machinery, buildings and technology then farmers, followed by downstream slaughterers, processors, distributers, retailers, food service and hospitality businesses. This chain in the EU provides products and services which 500 million Europeans palpably enjoy daily and want to buy, and in the process, makes a significant contribution to economic and community life and employment. However, citizens pressure for the alleviation of environmental and health damage from the production of livestock products they buy and consume must become the predominant driver for change.

This may well, initially, sound deeply unwelcome from the production perspective. Demand is projected to contract as costs are increased to meet higher environmental and health standards. Internalising more of the externalities of livestock production through full social cost accounting will thus itself reduce consumption. Bringing about buy-in from the production sector will be hard to win. Yet constructive change will go better and faster once producer interests are persuaded that the changes are unavoidable as the present trajectory of livestock production and consumption is simply unsustainable. There is no disguising that this challenge is difficult: new livestock production modes will require new science and technology, which, in turn, demands research and investment. This will be hard to secure in a sector initially expected to contract. This is why public policy must lead this process to push the transition into motion whilst proactively offering assistance to sectors which have to adjust.

The aim should be to emphasise the positive reasons for the change, to improve health and the environment simultaneously whilst developing new technologies and new markets for plant based protein, novel and synthetic protein, algal and insect protein and changing the character of continuing conventional livestock production.

A realistic period for the change is measured in decades. This offers time for changes in technology, institutions and social attitudes and behaviour. Reflection on examples of three areas which have seen, or are seeing, profound change illustrates the possibilities. First, computer power, communications and social interactions have changed out of recognition since the late 1980s affecting the whole population. Second, consider how cigarette smoking passed from the height of style and chic on stage and screen, and how the tobacco industry propelled advertising in the most popular sports in the world, and now smoking in public has all but vanished in increasing numbers of countries. Third, observe how the fuels which propel our transportation are changing, and will change, in the space of 2 or 3 decades. This is sufficient time for the kinds of change under discussion for livestock.

Meanwhile, the human population continues to grow. Every effort of economic policy will strive for incomes also to grow, and this will fuel further dietary convergence and transition in poorer and middle-income countries. The end to poverty and to malnutrition especially in the form of development-retarding lack of calories and protein are the first two Sustainable Development Goals. Who knows? These ambitious aims may be achieved. But it will mean an expansion in the consumption of food, and unless attitudes and customs change profoundly, this will include a large increase in livestock product consumption and production too. Consumption in countries already over-consuming livestock products, which includes most of the EU, must therefore at the same time adjust downwards to find a feasible global balance. In short, the livestock challenge is already huge, and it may well grow further before the corner is turned to bring livestock into their safe operating space.

The challenge is complex because livestock production and consumption is multi-faceted, each factor is itself complex and the interactions between them are not fully understood. This will have become apparent from the previous chapters. The connection between over-consumption of livestock products and human health is complex. So too are the connections between livestock husbandry and animal health management, anti-microbial resistance and impacts of zoonoses. The principal production challenges for livestock, namely suppressing methane, managing plant nutrients, locating and housing animals, processing manure, breeding and feeding animals to improve conversion efficiency and live weight gain, and reducing waste. These all involve complex relationships. The interactions between these considerations and our willingness to subject animals to close confinement and restrict transport of live animals add further complications. It is tempting to try and simplify and focus on one or a small number of key issues, for example GHG emissions, but this will not work because the dangers of worsening some other concern are real and the interests in other issues like animal welfare are too strongly felt. A system approach involving consumption and production and all participants in the chain is unavoidable.

Two initial conclusions from the scale and complexity of the change required are, first, that there should be a **public awareness raising effort** to explain and debate the long-run changes which will be required in livestock product consumption patterns and the reasons for this. Second, **more research** should be conducted to fill in the gaps in understanding and to better quantify where the safe operating space for livestock lies and the adaptations required to move towards this space.

Whilst the livestock challenge is not new to the agricultural research community, nor to stakeholder groups in food and farming, it lies largely outside discussion in the EU political arena and the general public across the EU. Two examples will illustrate this. For the EU27, neither the Commission's communication (November 2017) on the future modernisation of the CAP for the period 2021 to the end of 2027, nor the preamble in the proposed regulations for the new CAP, make any specific reference to the scale of adjustment required in EU livestock. Similarly, in the spring 2018 consultation paper for UK post-Brexit agricultural policy called Health and Harmony, there was no reference to a livestock challenge. The livestock debate has hardly surfaced in mainstream discussions and debates of European agricultural policy. It is essential that the awareness of this issue is raised in public consciousness. A remarkable exception, and exemplar, is provided in the recent report of the Dutch Council for the Environment and Infrastructure (2018) which explains the nature and scale of change required in Dutch food consumption and production. This report majors on the challenge of livestock. For a country which has one of the most intensive, and export oriented, livestock sectors in the world to admit that it is not sustainable and must contract in future through the reduction in animals and in farm numbers is bold and courageous.

Public authorities must take a lead in awareness raising and be actively engaged in spreading information and knowledge of the issue through the public education system and health services. But it is not just a task for governments and public agencies. It must also involve many civil society groups and opinion formers. Together this will alert businesses in the food chain to consider how they will participate in making the transition. The EU has a special role to play in this because it has a highly developed livestock sector, has high livestock consumption levels and intensive production systems, and is a large player in the international trade of animal feed and livestock products. There will of course be strong defensive warnings issued by livestock producer interests that pursuing these issues may simply export livestock production, and the associated environmental damage and lose jobs and economic output in the process. This issue is confronted in section 5.4 below.

This study has not expressed the scale of change beyond very broad orders of 'livestock' magnitudes and has not attempted to disaggregate by species and farming systems. Apart from the study's small resources this is for several reasons:

- It is very difficult to do with any precision, there are gaps in concepts and data.
- Objectively calculable boundaries (or turning points or thresholds) have, so far, only been suggested for three of the eleven variables identified.
- It has not been possible to cover: fish, water use and availability, biodiversity.
- There is great uncertainty about the possibilities for large scale technical breakthroughs, the acceptance of their results and economic viability.
- The reactions and interactions between the EU and the rest of the world have not been incorporated.
- The analysis for some variables, especially water pollution, biodiversity and land degradation, should be conducted at lower, regional, level to capture river basin level water pollution concerns and rebalancing the geographical distribution of livestock.

How to sustain confidence for continued investment in the sector whilst managing the change envisaged to maintain a core and profitable livestock sector also requires considerably more thought.

Although the 'livestock challenge genie' is now well out of the bottle, it has not yet been seized by European governments as an identified strategic policy issue. The dangers of the principal negative impacts of livestock are well analysed in scientific literature. Environmental NGOs have long campaigned on the issue. However, livestock has not yet enjoyed its 'Blue Planet' moment as occurred for plastics when public and governments seize this as a strategic issue deserving real action. To date neither EU policy nor that in MS have yet chosen to focus public attention on 'the livestock problem' as such. It is now time to do this.

Because the adjustments suggested are so large this is deeply uncomfortable to producer interests in the whole livestock chain, who are very aware of the criticisms. The authors are also acutely aware of the already precarious nature of the farm-level economics of many livestock businesses, and their vulnerability to volatile feed, milk and meat markets. The response from the productions sector is, not unnaturally, a mix of denial that the sector is not in a SOS, claims the negative impacts are exaggerated, but also acceptance that some reaction is needed, but technical progress will be sufficient to put things right.

These observations prompt the primary conclusions and recommendations of this report:

R1 The EU should set up a formal inquiry to investigate the following questions.
- ***Where is the safe operating space for EU livestock?***
- ***What adjustments in production and consumption are necessary to get into it?***
- ***What policy measures would be required to propel these adjustments?***
- ***What would be the impacts on health, environment and the economy of these changes?***

The sheer immensity and complexity of the livestock challenge, and the needed response, is such that public authorities must be prepared to take a bold initial step to overcome the inevitable inertia. Without such a jolt or shock there will be insufficient action.

R2 It is suggested that the change must be a citizen-led, consumer-led, enterprise. Although it requires action by both consumers and producers the transition required will only occur if driven by consumers. This will not happen spontaneously but only if Government takes strong action to spur the necessary changes.

5.2. Encouraging sustainable consumption of livestock products in the EU

Changing consumer behaviour is not straightforward as it is influenced by a long list of interacting factors ranging from personal factors, such as the genetic disposition to prefer certain tastes and macronutrients to contextual factors, such as the role of particular foods in national and regional identity and culture (see Box 1) (Story et al., 2008). This is certainly the case for livestock products in general and for meat. While there is a steady rise in protein consumption worldwide, Sans and Combris (2015) showed that meat consumption patterns vary significantly among countries. Even when different income levels are accounted for, history, geography (land-locked vs near sea), culture and religion lead to quite different consumption patterns. Leroy and Praet (2015) particularly point to the human legacy of meat traditions, as seen in hunting, slaughtering, eating and sharing activities, rituals and rites. De Boer and Aiking (2018) found both a north-south and an east-west gradient in meat consumption and behavioural trends within the EU.

Given this wide range of influences on what people eat it is probable that a wide range of tools will be necessary to help them change what they eat. The approaches will also be different when the reasons for changing consumption are to do with consumers own health and that of their family, as opposed to environmental, climate and animal welfare concerns. It is often said that governments are reluctant to intervene in individual consumption choices, fearing accusations of being the "nanny" state. However, over time there is general acceptance that responsibility for the greater good and tackling well-evidenced health, environmental and animal welfare harms justifies collective action. Many authors have addressed the range of such actions and the principal actors who should be involved.

A recent Chatham House Report (Wellesley et al., 2015) argues for robust, interventionist measures supported by awareness raising. They categorised three groups of actors: Non-state - business and civil society, Governments and Collaborative. They classified interventions into three groups as shown in Table 6 illustrating the range of actions available to each actor under each of the intervention types. The first is to inform and empower, which can be done through labelling and information campaigns. The second is to guide and influence, which can be done by changing consumers' choice architecture (i.e., nudging). The, third is to incentivize, discourage or even restrict, which can be done through taxes, subsidies, bans or standards. These interventions will have a range of effectiveness with different demographic groups.

The softer, informational and guidance, tools must be consistently applied over long periods, and the messages refreshed periodically with developing knowledge to ensure they still command attention. These are the least controversial measures. All actors have important roles to play. Governments could better explain dietary guidelines perhaps making them more detailed than at present and tuned by gender, age and activity. They can also provide more tangible guidance by acting on school meals, public procurement and menus for all state institutions. Training of teachers and development of school curricula have a role to play, and this should involve parents too. Developing the narrative of how society has slid unwittingly into harming human health and the environment by its food choices is a complex story but it is vital that the public is informed why all the measures under discussion here are being deployed. The private sector food industry and food service also have a vital role to inform choice through product labelling and information. The aim must be to make it easy for consumers to make healthier choices. The private sector can constantly update no-meat or less-meat menus and recipes, backed by popular

Table 6. Spectrum of interventions to influence consumer behaviour (adapted from Wellesley et al. 2015)

Actors	Intervention type		
	Inform and empower	Guide and influence	Incentivize, discourage or restrict
Non-state (business and civil society)	• Product labelling and content advice • Information campaigns	• Preferential positioning of desirable products in retail settings • Reduction in plate and portion sizes in restaurants to aid lower consumption volumes • Pledging of behavioural change in institutions or campaigns for change in public or private sector	• Voluntary commitments to use more or only sustainable, healthy products • Public campaigns calling for changes to menus in public institutions
Government	• Public information campaigns • Advertising regulations • Labelling regulations • National or individual nutritional guidelines	• Change in default food purchase options for consumers • Change in default food options in public institutions	• Ban or tax on unhealthy or unsustainable foods • Subsidization of healthy and sustainable foods • Inclusion of standards on sustainable, healthy foods within public procurement guidance
Collaborative	• Agreements on standardized labels • Multi-stakeholder nutritional guidelines schemes	• Agreements on range of menus	• Multi-stakeholder agreement on restrictions for the sale or advertising of undesirable products

personalities and chefs, and of course provide training for caterers, cooks and chefs.

Transparency in the food chain will be an important aspect of enabling consumers who hear about and are concerned about the health and environmental impacts of their food choices to act. Publicly and commercially inspired food labelling initiatives are part of this but can be cumbersome and not always trusted. Big data, more direct selling and shorter supply chains are some of the many ways of segmenting the market and encouraging niches for products which allow consumers to discriminate on attributes relating to health and environment.

Of the harder, more strongly biting measures, it will usually be easier to assist the development of new technologies than to curb harmful old ones. That said, there has been progress by governments working with the food industry to reduce salt levels in processed food from bread to snacks (DG Health and Consumers, 2012). Doing the same for sugar is relatively more recent but is beginning to get traction (UNESDA, 2017). These two examples of food industry action are motivated by concern for consumer health, it remains to be seen if similar persuasion can work when the objective is reducing environmental damage. Meanwhile, at the very least environmental harmful subsidies where they exist should be curbed[137]. Governments seem initially reluctant to go beyond this. But this was also the case for tobacco smoking, and car seat belts, until, at some point, society can appear willing to absorb stronger measures.

The economic argument of internalising externalities by taxing polluting products and processes is strong: it encourages consumers to switch to cheaper less-polluting alternatives, on the production side it encourages managerial and technical change to reduce the pollution, and it raises revenues which might be deployed to help producers adjust. There are several ways to do this, by using differential Value Added Tax (VAT) on livestock products compared to other foods, or by specific excise duties as is done with alcohol and tobacco. Alternatively, if the greater problem is carbon, nitrogen or phosphorus pollution, then taxes on these pollutants might be a more direct approach.

Such proposals to help implement the polluter pays principal by taxing pollutants have been aired by economists

137 This mostly refers to production subsidies which are dealt with in sections 5.3 below.

for a very long time. However, in practice it appears hard to impose such taxes on food or in the food system. The reluctance is partly a general fear of causing food price inflation, given the knowledge that food taxes will be regressive, hitting poorer households most (e.g. the elderly, unemployed, disabled, and those with more children). This is because such households spend a higher proportion of income on food. In principle, this problem can be dealt with by appropriate redistribution through taxes and social provision. Such offsets are easier to describe than to implement and convince the public. Ultimately these matters, the effectiveness and distributional impacts, for example of taxing polluting or environmentally harmful products (such as red meat, processed meat) versus subsidising alternative protein substitutes (such as alga-culture, insect or synthetic meat culture) must be decided by analysis and evidence (Caillavet et al., 2016). This should include estimating the costs of inaction. Such taxation would be in line with general ideas about greening the tax system, moving taxes from labour to consumption and use of materials.

It is concluded therefore that:

R3 A mandated output of the proposed inquiry should therefore be a suggested set of policy proposals which include measures to discourage consumption of livestock products harmful to health and environment and to encourage consumption and production beneficial to health and environment.

Garnett et al. (2015) carried out a comprehensive literature review on what kind of interventions are effective in changing diets. Unfortunately, they conclude that the evidence base for interventions to reduce meat consumption is limited, which can be explained by the lack of willingness of policy makers to engage in interventions on diet in the first place—thus creating a cycle of inertia (Wellesley et al., 2015). The main lesson from other initiatives aimed at changing food consumption (e.g. sugar, fruit and vegetables, palm oil, fish) is that a mix of approaches is needed for change.

Based on their study or meat consumption in the Netherlands, in which they found different modes of flexitarianism[138], Dagevos and Voordouw (2013) argue in favour of an incremental approach towards reducing meat consumption to break the cycle of inertia. They argue that such a position better connects with the current reality of consumer and NGO initiatives towards meat reduction and of companies making meat substitutes more attractive.

138 Flexitarianism refers to consumers who limit their meat consumption at certain days of the week, rather than becoming full-fledged vegetarians. Many initiatives (e.g. Meatless Monday) appeal to this incremental change strategy.

In summary, consumption behaviour will change when consumers are convinced such change is necessary and it becomes socially unacceptable to continue old practices. Governments, the food industry and civil society have a wide range of tools to help make this happen. But they need to be convinced too, this is the purpose of the recommended formal inquiry.

5.3 Encouraging sustainable production of livestock products in the EU

The most helpful first step in making the transition to the Safe Operating Space for livestock would be public acknowledgement by producer interests that the EU livestock sector is not already in this space and that a long-term transformation may be needed to move to this space. Defensiveness, or denial of this, however understandable, will be a barrier to action to bring the sector into its SOS. There *is* recognition by farmer organisations that farming must "impact less" acknowledging that crop and animal production must improve their environmental performance by reducing pollution of atmosphere, water and soil and better caring for biodiversity. This is genuine. However, such recognition is nearly always in the context of urging policy makers to recognize the challenge of "producing more" to cater for the still growing world population. It is rare for farming organizations to question the very environmental sustainability of their sector, although they will readily point to economic unsustainability in times of low prices or for marginal activities such as extensive beef and sheep production. It seems unlikely that they can acknowledge the need for contraction in the livestock sector in Europe[139]. There are few signs of recognition that the expansion of consumption of livestock products has gone beyond what can be produced without unacceptable damage and that consumption and production must be pulled back. Indeed, the regulatory efforts to curb pollution and biodiversity destruction through amendments to the CAP in the 2013 reform were vigorously and successfully, weakened in the legislative process (Swinnen, 2016). This stance was defended on the grounds of food security which is equated with a need to produce more to feed the world. There is no recognition that by curtailing livestock production for the high consumption countries this would release resources to feed the growing world.

139 It is readily acknowledged that this is a highly stylised representation of the wide range of views of the many farming organisations in the EU. It characterises the approach of the main umbrella organisation COPA-COGECA which has always been very reluctant to accept the need for change in agriculture or its policy. They are usually supported in this by the immediate up and down stream suppliers and first stage processors. However, there are many farmers' organisations, and of course farmers, who are well-aware of the need to minimise environmental and climate damage and who fully subscribe to the necessary steps to work towards more sustainable farming systems.

It is probably too much to expect that such a well-established sector as livestock can be persuaded by evidence that it is unsustainable and must change and contract. Such evidence must nonetheless be repeatedly assembled and presented[140]. A difficulty, as discussed in Chapter 3, is that global, EU and local thresholds are not crisply and clearly defined and not precisely measured. This is especially so for nutrient flows. The existence and scale of the boundaries can therefore be challenged. The conclusions of this and other papers which argue for reduction in livestock consumption is a judgement. Its main basis, with considerable quantitative evidence, are the direct and indirect greenhouse gas emissions associated with livestock production and the case is bolstered by consideration of the many other factors: health, nutrient flows, soil and biodiversity degradation and animal welfare. But judgement it is, which of course can be contested. This assessment of the general stance of producers leads to the conclusion that the focus of policy should first and foremost be on making the scientific case to *the public* for reducing livestock product *consumption* rates. If enough of the public can be convinced, the policies and actions to help change consumer behaviour will be enacted, and producers will then have little choice but to follow the market. If the public cannot be convinced, then the world will continue to suffer the environmental and public health consequences.

Meanwhile however, and regardless of the success in bringing about a change in consumption behaviour, it is necessary to promote the actions necessary to bring livestock into its safe operating space. It is therefore recommended that:

R4 Policies must encourage: structural change in farming, resource efficiency improvements and reduction of leakage and waste.

The Structural changes, are required to bring about a better balance, structure, location and de-concentration of livestock and better integration of crop and animal production. The resource efficiency improvement is required in crop production, pasture management, livestock breeding, feeding and housing, and upgrading manure processing to recover and reuse nutrients. The leakage and waste reduction are necessary to protect and ameliorate soils, water, air, biodiversity and landscape quality.

There is a wide range of policy areas which must be brought to bear to encourage these necessary actions. It is encouraging, but also dispiriting, that most of the policy actions are familiar. Many are already in place so no great shocks are in prospect necessitating new legislative structures. But the fact that some, for example the EU's 1991 Nitrates Directive, have been in play for so long and yet has not sufficiently curbed the surplus of nitrates in water and air, indicates that there are some deep-seated difficulties in enforcing environmental regulation. This explains why, without radical change in mind set and perhaps also incentive structures, it would be unrealistic to expect radically different rates of improvement in future. If farming interests want to avoid the conclusion that total livestock consumption and production must fall to curb environmental damage, then they must demonstrate that action focussed on production alone can get livestock substantially back into its SOS. This will require a very different attitude and response to environmental protection than has been evident to date.

The relevant policy areas to help livestock move to its SOS are considered under five headings: environmental, agricultural, animal health and welfare, R&D and technology, and food chain engagement. Human health, nutrition and wellbeing are considered to have been dealt with under consumer policies in section 5.2. None of the five areas will be discussed in detail although it is recognised that the impact of livestock emissions on human health is a strong driver for change in the sector. Each is a large and complex subject with extensive literature on what has been enacted, achieved and remains to be done. These five areas all have some basis in EU legislation but their implementation is of course managed by national and regional authorities and ultimately by farm businesses and agribusiness and by civil society groups on the ground. The very act of listing the five areas together indicates the breadth of the task and underlines that without a strategic acceptance and statement of where we are heading and why, and the scale and nature of change required, it will be very difficult to arrange a coherent mix of these policies.

Environmental policy, including climate

Apart from soils, each of the environmental media is already the subject of EU legislation. The requirement for environmental policy is the simplest to state, yet evidently, amongst the hardest to achieve. It is to reach the EU goals set under International Agreements, regulations, directives and policies by rigorously enforcing existing policy: Climate Action[141], the Water Framework Directive (2000/60/EC), the Nitrates Directive (91/676/EEC), the Nature Directives (Birds 2009/147/EC and Habitats 92/43/EEC), the Sustainable Use of Pesticides Directive (2009/128/EC), and air quality directives (Ambient Air Quality Directive 2008/50/EC), and the National Emission Ceilings Directive (2001/81/EC). Precisely because environmental legislation mostly takes the form of directives in which MS choose the means of achieving the agreed EU objectives and tar-

140 As this chapter was written publicity was given to just such an exercise by Poore and Nemecek (2018).

141 https://ec.europa.eu/clima/index_en

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gets there is great variability in the vigour and effectiveness towards achieving the goals. This is well illustrated in the comparison of progress in Denmark, the Netherlands and France in reducing nitrogen pollution from livestock production in those countries analysed by Le Goffe (2013). This study contrasted what the author saw as a tougher implementation of the nitrates directive in Denmark and the Netherlands leading to better environmental results than the avoidance approach in France. Le Goffe recommended five changes to bring about better results.

- Effectively apply regulations, by defining the right ecological standards and sanctions.
- Expand sensitive zones, where stricter measures would be applied according to ecological issues.
- Simplify regulations, by eliminating measures that unnecessarily limit farm restructuring.
- Facilitate manure transfers, to help minimise manure disposal costs.
- Compensate income losses temporarily but without creating distortions.

This revealing case study lends support to the proposition that progress on implementing environmental regulation is dependent on winning a change in mind set amongst farmers. However, it is interesting that more environmental progress is judged to have been made in the case of Denmark and the Netherlands where the Government was prepared to be more confrontational, than in France which tried to be more participatory in working with farming organizations. If these organizations are not convinced there is a need for more fundamental longer-run change to work towards sustainable production then they tend to work to minimize short term changes which they see as unnecessarily adding costs and trouble for their businesses.

There is a large literature on ways to reduce negative environmental impacts of livestock production. A classic and much debated approach favoured by economists is to tax polluting inputs, such as manufactured fertilisers and pesticides. With cost-effective inputs, such as nitrogen and crop protection chemicals, the tax rate may have to be high to have much impact on usage rate and thus leakage and pollution. A high input tax is generally resisted by farmers and input suppliers; although such taxes with price inelastic demand will raise revenues.

An alternative approach is to encourage more precise application of inputs to minimise leakage, this is a key aspect of what is currently referred to as precision agriculture. An initial step in this process is to ensure that all land managers are aware of the flows particularly of nitrogen and phosphorus through their businesses. This can be done by requiring and helping farmers devise detailed nutrient management records and plans tracing the inputs of fertilisers, manures and feeds and the fate of the key nutrients. This help farmers understand how much is contained in their marketed animals, crops and products, and how much results in leakage to atmosphere, soil and

water. Such accounts can also play a part in legislative control (Breembroek et al., 1996). The digital technologies to measure and analyse inputs and their effects are greatly helping these improvements. Based on the principle that farmers cannot and will not manage what is not measured, farmers can also be helped, or required, to assess the greenhouse gas accounts of their business and other pollutants such as ammonia. Only when most farmers are keeping such environmental accounts alongside their business accounts can the process of establishing reliable and sufficiently differentiated benchmarks for different farming systems in different environments be established. This can then lead to a virtuous circle of improvement. There are many options for implementing such procedures and the management follow-ups. It can be helped through commercial contracts enabling processors to claim they are sourcing more sustainable food ingredients. It can be part of the conditionality for the receipt of public payments to farmers, or it can be entirely voluntary relying on the win-win for farmers that they only apply inputs justified by measured outputs and is part of the move to precision farming of crops and animals.

A further approach which has application at both farm level and more broadly for the food chain is to embrace the principles of waste prevention and reduction and the circular economy. This approach would seek new business models which build-in material recovery and reuse by design. There is much general support for these ideas in the EU, but it is still early to measure impacts. Waste reduction principles are enunciated in the Thematic Strategy on the prevention and recycling of waste (COM/2005/0666 final) and associated regulation, and the recovery and reuse of nutrients is a key mentioned area in the circular economy action plan (COM/2015/0614 final). The 2016 RISE report on the recovery and reuse of nutrients in the EU offered recommendations on how to make progress in this area (Buckwell and Nadeu, 2016).

In summary the key recommendations for environmental policy are to:

R5 Implement existing environmental regulations and directives.

More specifically,

R6 Help farmers better manage the environment on their farms by assisting establishment of better farm-level environmental performance indicators, benchmarks and plans for GHG emissions, nutrients and biodiversity.

Agricultural policy

The EU's long established, generously funded and highly developed Common Agricultural Policy (CAP) contains a framework for national authorities to be in annual communication with all individual farmers in their jurisdiction who manage more than a minimal small area. It includes a land parcel identification scheme which records all the fields with agricultural land. The CAP has been through a sequence of reforms since the mid-1990s in which it has broadened and changed its structure from being a commodity market support policy to a two-pillar apparatus focused on viable competitive farming, sustainable management of natural resources and climate, and balanced territorial development. In principle, and with one important exception, it contains all the measures necessary to help all farming, not just livestock farming, manage their land and businesses sustainably and to make the transition into a safe operating space. It is therefore not necessary to invent a brand new agricultural policy, but to utilise the resources it deploys and measures it contains much more purposively towards strategic objectives. The 2017 RISE Foundation report on the CAP (Buckwell et al., 2017) particularly focussed on the inefficient use of the funds allocated to direct payments, especially coupled payments. These resources could and should be far better utilised if targeted towards helping farmers make the transition to sustainable farm businesses. The principal recommendation for agricultural policy is therefore to:

R7 Better target the Pillar 1 resources currently provided as direct payments, by deploying them to stimulate and enable structural changes required to help the livestock sector make the transition to a SOS.

The first Pillar of the CAP comprising direct payments to farmers and a regulation for Common Market Organisation (CMO), is funded entirely from the EU budget. This accounts for about three-quarters of the CAP annual expenditure. The second, Rural Development Pillar, contains most of the structural support measures and is cofinanced by the EU budget and the MS. The CMO regulation allows interventions in commodity markets in extreme market situations. Most of the resources of Pillar 1, amounting to over 70% of the total EU CAP budget, are devoted to annual payments to farmers. These are based on the area of agricultural land under each farmer's control. The payments are (mostly) not coupled to agricultural production, but are subject to a series of mostly environmental cross compliance conditions. The direct payments currently comprise a basic payment (taking around 60% of Pillar 1 funds), a greening payment (30%) and, at the discretion of the MS, smaller amounts for small farmers, young farmers, new entrants, payments coupled to certain production, and to farmers in so-called less favoured areas which are subject to natural constraints (remote and mountain areas). The complex development of these payments is well documented in Swinnen (ed) (2016, 2008), and a detailed analysis of their poor current performance is provided by Matthews in Buckwell et al. (2017)[142].

142 See Appendix 1 in Buckwell et al. 2017 'Why further reform?' (2017) http://www.risefoundation.eu/publications

The Pillar 1 direct payments provide a substantial part of farmers' incomes, averaging 45% across the EU in the last period. This share of income varies widely by farming type and region from under 10% for poultry and some horticultural farms to over 100% for grazing livestock farms. The cross-compliance conditions, bolstered by the greening payments introduced after 2014, were intended to raise the environmental performance of EU agriculture to work towards the targets of environmental regulations. However, reports from monitoring and evaluation, the European Court of Auditors and numerous research projects have shown that progress in this direction is slow.

The Rural Development second pillar of the CAP operates on a multi-annual (7 year) programming basis, and has 6 operational objectives[143]. The Member States define Rural Development Programmes either for their whole territory or on a regional basis in which they choose to offer their farmers support from a menu of 20 measures based on their assessment of national/regional needs. The measures cover schemes supporting investment to improve efficiency, productivity and viability of farming by helping knowledge transfer, advisory services, physical assets, quality schemes, marketing of agricultural produce, producer groups, risk management, training and skills enhancement. All MS are obliged to offer agri-environmental and climate measures which are voluntary for farmers and offer them the possibility to be paid through multi-year contracts to provide public environmental services, to convert to organic production, improve animal welfare, to make so-called non-productive investment in environmental protection, to protect the designated Natura 2000 areas, and in some, forest environmental and climate services, and forestry conservation. There are also measures to encourage local development, basic services and village renewal, rural infrastructure improvement such as broadband and mobile communications, and renewable energy.

This comprehensive collection of measures under the two-pillar CAP has evolved in several stages since it was introduced in 2000, and is expected to be further modernised from 2021 under the proposals for further reform which were published in June 2018[144]. The main elements of the proposed reform do not fundamentally change the basic two-pillar structure outlined above[145].

143 For details, see the ex-ante evaluation of the 2014-2020 Rural Development Regulation in European Commission (2015). This describes how the MS implemented the regulation in 118 Rural Development Programmes for the current period.
144 See: http://europa.eu/rapid/press-release_IP-18-3985_en.htm
145 There is no change in the core financing arrangements, although co-financing of Pillar 2 is proposed to be cut, and the proposals for the 2012-27 Multiannual Financial Framework proposes a 5% cut in CAP funds in current Euro (and therefore a larger cut in real terms). The bulk of Pillar 1 will remain with annual payment entitlements for farmers and pillar 2 with multi-annual programmed measures. But as a break from the past performance in both pillars and not just Pillar 2 will be subject to monitoring and evaluation.

The most important change proposed is a new delivery model which requires MS to produce a strategic CAP plan based on a needs assessment which will deliver objectives and targets defined in the regulation for both Pillars at EU level. This devolves responsibility for designing the detailed measures in both pillars to the MS. There are also proposals to: abolish the ineffective compulsory greening payments, and substitute a voluntary eco-scheme in Pillar 1, to redistribute more of the direct payments from the largest to the smaller beneficiaries, and to give greater emphasis in the policy to payments to farmers for delivering public environmental and climate protection services.

The CAP already contains the main kinds of measures which might be required to steer agriculture especially livestock into its SOS. A critical exception, which was flagged in the 2017 RISE report on the CAP (Buckwell et al., 2017), is the diagnosis of the scale of the transformation required and consequently the recognition that this transition will require significant structural change in farming and thus assistance to foster the transition of farm businesses to a sustainable basis. Such businesses should not be undermining the soils, biodiversity, clean water and climate on which they depend, they should be commercially viable without annual handouts, and embedded in lively, diversified rural communities. The CAP is the correct and obvious policy framework to provide the assistance that will be needed to bring this about.

Only when it is openly recognised and explicitly acknowledged by the agricultural policy community in the EU that the balance of the agricultural sector must radically change to reduce the negative impacts of livestock will it be possible then to plan for the adjustment assistance required. Indeed, it was always envisaged by the first Agricultural Commissioner, Sicco Mansholt, in the 1960s that market policy should be an accompaniment to structural policy to modernise agriculture. The problem was that from the outset, others had different ideas and the reverse came about: market policy dominated structural measures since the origins of the CAP in 1958. The scale and distribution of the direct payments were based, and are still rooted, as backward-looking compensation for the removal of price supports from 1995 to 2005. They are not constructive, forward-looking, transitional adjustment assistance. This is the principal change still to be brought about.

To remedy this shortfall in policy geared towards helping farming find its SOS, demands much fuller analysis than has been provided here. Such analysis must be conducted at Member State level to identify the scale and nature of the safe operating space for livestock. This in turn will help identify the changes to businesses up- and down-stream in the food chain which will also have to adjust. The SOS will look very different across Europe because consumption patterns, productions systems and agricultural resource endowments are different around the EU. Some livestock activity will have to contract and disappear, some will have to relocate, change size, change technology – feed and feed system, housing manure management, and some businesses may grow. The pattern will differ from region to region. There will inevitably be stranded assets in some sectors which will contract, these assets will be found on-farm, up-stream and down-stream.

The wider effects of contraction in farm livestock are far from trivial. The fact that farm added-value is such a small part of consumer expenditure on food is an indication of the scale of the economic activity which surrounds primary production. In addition to the often highly specialised businesses up and down stream which partner the main stream production of meat, dairy products and eggs, there is a wide range of co-products obtained from livestock, many of which are used in industrial processes. In addition, there is a large industry providing pet food. In the US, pets consume 25% of the calories from all produced livestock, and although in many cases they eat parts that humans don't want to eat, their contribution to total GHG emissions is also substantial (Okin, 2017).

Agricultural policy should be available to assist the restructuring developments on farm. Other regional policy instruments may be required to help the up and downstream sectors. This again indicates why the livestock challenge must be addressed as a cross sectoral strategic issue and not simply as a problem for agriculture. The key is to deploy adjustment assistance in the form of retirement assistance, restructuring and relocation help, this can be done by loans and maybe some investment grants. This should be available to help those who have to leave livestock production as well as those who will remain but restructure. Often, structural change in farming is inhibited by practical concerns such as rehousing the retiring generation, or by tax and pension considerations. Agricultural and wider restructuring measures should be capable of reaching all dimensions necessary to unlock the necessary changes.

These are big challenges, politicians dealing with agriculture have always found it difficult to deal frontally with the notion that their job is partly to enable, and indeed to encourage, the outflow of poorly remunerated labour. The result is an over-manned industry with too many non-viable businesses trapped in dependency on CAP direct payments who are tempted to intensify their production to make a short term return but in the process imposing long-term damage on natural capital. Only when it is acknowledged that this is a trap and substantial adjustment is required can the abundant resources which the European taxpayer patently is prepared to make available be better deployed to assist the required transition. Recognising the livestock challenge could be the needed catalyst to initiate the further reforms required.

Animal health and welfare

Regarding animal welfare, there are currently five European Union Directives relating to farm animal housing, with 98/58/EC covering general rules for their protection and the others covering laying hens, pigs, meat chickens, and calves (Humane Society International, 2016). There are also Directives for animal transport and slaughter. These set minimum acceptable standards across the EU, although individual MS may, and some do, go beyond these standards. Examples include the banning of de-beaking in Finland and Denmark, and the banning of duck and goose force-feeding under the German Animal Welfare Act (Tomaselli, 2003). The EC's 2000 White Paper on Food Safety recognised animal welfare as a key component of EU food policy, as does so the recently established EU Platform on Animal Welfare[146]. EU legislation is evidence-based. It was formalised in 2002 with the creation of the European Food Safety Authority EFSA. Compliance is monitored by the Commission's Food and Veterinary Office, which conducts on-the-spot checks in MS (Horgan and Gavinelli, 2006). The Standing Committee on the Food Chain and Animal Health provides a platform for MS to discuss issues and approve urgent measures, making the process collaborative (European Commission, 2017b). Animal welfare is not covered by the General Agreement on Tariffs and Trade 1994, nor in other WTO agreements, and it is up to individual trading countries to negotiate trading conditions (Horgan and Gavinelli, 2006).

Some of the issues surrounding the treatment of animals kept in intensive farming systems are addressed by the relevant legislation, while others are accepted practice in the industry and thus no regulatory action has been taken. One gap is the lack of mandated pain relief in procedures involving removal of body parts, including tail-docking and beak clipping. Another area of concern is the premature deaths of animals used in milk and egg production. Current legislation deals mainly with the external parameters of animal suffering, such as cages and crates, and has yet to codify the more complicated area of direct indicators of suffering such as stress levels, the strain of overproduction, and anti-social behaviours. The emotional or affective state of animals in intensive systems is difficult to establish and has yet to be included in welfare definitions or regulated in the EU. Voluntary welfare labelling schemes, such as the EU-funded Welfare Quality Project and national schemes in the UK, Germany, France and The Netherlands, are attempting to codify welfare indicators for consumers (Katsarova, 2013)"event-place":"Brussels","URL":"http://www.europarl.europa.eu/RegData/bibliotheque/briefing/2013/130438/LDM_BRI(2013. While no EU-wide scheme is in place, a 2009 feasibility study found that a label modelled on the EU Organic Label could provide a good solution to increasing consumer awareness and incentivising producers to improve standards in their operations (European Commission, 2009).

The changing social climate is placing increasing pressure on industry and government to address the livestock problem and addressing animal welfare is a prominent aspect of these concerns. The relationship between animal welfare standards and environmental protection and improving human health outcomes have not been explored in detail. There has been a growing understanding of the impacts of intensive livestock production on the environment and more recently, on human health[147]. Current research addressing trade-offs between animal welfare, farm productivity, and environmental protection may provide direction for future policy initiatives in the EU. The brief example of dairy cows grazing in the meadow illustrates some choices. This is generally held to be good for animal welfare but with high stocking rates it may not be so good for careful control of manure, and it may be less attractive economically for farms with robotic milking. Climate change adds a further complicating element, as the hottest and coldest regions will likely face increasing difficulties in meeting animal welfare needs due to extreme temperatures, also climate change brings with it higher disease risk. The combination of human population and income pressures driving growth in food demand, together with climate variability, and farming and food industry pollution and emissions, it is important that animal welfare is also integrated into policy and research aiming for a more sustainable future.

Research, Development and technology

The proposed inquiry will discover that there are gaps in our understanding of many issues and data gaps, one of its tasks must therefore be to identify the research agenda and data collection necessary to guide action. Additional research is required to address the livestock issue in all its dimensions. A first task is to elucidate global and regional boundaries and the more precise identification of the SOS for Member States and regions.

> ***R8 An important task within the proposed inquiry is to develop a better conceptualisation and measurement of the ceilings or upper boundaries of the safe operating space especially with respect to nutrient flows and biodiversity.***

Research on greenhouse gas emissions from livestock in the last two decades has delivered assessments and datasets but further effort is needed to combine direct

146 https://ec.europa.eu/food/animals/welfare/eu-platform-animal-welfare_en

147 Human health is affected through the use of antibiotics in meat, the use of chemicals in processing, and the possible impacts of stress on meat when ingested.

and indirect emissions from livestock and to account for improvements in the sector. Farmers must be credited with any improvements which are made in reducing the emissions per unit of their production.

R9 It is essential that GHG emission factors for livestock are regularly updated to reflect the expected, and necessary systematic improvements in resource efficiency.

The flow of nutrients through food and farming systems has also been studied in detail at the EU scale but further research on local and regional impacts and establishing pollution thresholds to place an upper threshold to the nutrient boundary is needed. Less information is available on the condition of bird, insect and flora populations in agricultural ecosystems as affected by livestock, and methodologies to assess such impacts need further development. All these efforts must be encouraged as there are still doubters that the damage is serious or needs radical response.

A second task deals with the actions that can get livestock in its safe operating space and ensure it remains in it. This involves efforts to identify the production systems, in combination with technologies, that can reduce livestock's impacts and increase their resilience. Many of the actions outlined in Chapter 4 require new technological development. Three examples identified were: the development of new sources of animal feed and human food protein, the introduction of better environmental performance monitoring to guide more precision crop and animal farming, as well as the integration of both, and the encouragement of more nutrient recovery and reuse from food waste and human waste. There is a public interest in understanding how to master these developments and then to get them from the laboratory into commercial practice. It will also require assessments of the environmental, social and economic performance of the new products and processes in addition to impacts on human health, animal welfare and the development of new regulatory frameworks, such as those in preparation for novel organic fertilisers. Also, as infant industries operating on a small scale some of these developments will find themselves competing against established businesses operating at much larger scale and might therefore merit start-up assistance, investment support or favourable set-up tax treatment.

All these research developments, including the quantification of the boundaries, should take into account the changing conditions under which the livestock sector will be required to operate in the future, together with changing societal demands. Developing tools to assess the sustainability and resilience of livestock systems, regardless of its future projected scale, is of crucial importance.

Food chain engagement

It has been stressed that moving to a SOS for livestock demands mind set change by consumers and by primary producers of livestock, so of course it also requires the buy-in of all those engaged in the food chain between farmers and consumers, and upstream of farming.

To the extent that breeders, feed compounders, and suppliers of animal health products, animal housing and manure handling plant and machinery can help farmers know about and reduce their emissions, leakages and waste then they can reduce the extent to which livestock populations may have to be cut. The farm input suppliers, and to some extent the meat and dairy processors too, have long been the source of much of the innovation in the food chain including helping farmers produce to higher standards of efficiency, quality and consistency. Healthy, efficiently managed livestock will generally have a lower environmental impact per unit of product. So it is vital this continues. But it is not a comfortable combination for private investment to be associated with a sector expected to contract. Investors generally favour industries for which the long-term prospect is growth. This may mean that the public sector must be ready to step in to assist with the technical developments which formerly would have been expected to have come from the private sector.

A more positive side of the transition to lower livestock consumption is that somewhat more of the consumption which survives long term will be the higher quality, and therefore higher priced meat and dairy products. Maybe a higher proportion of the fewer meat-based meals consumed will be on special days of the week, month or year, when they are accompanied by more preparation and service, and more often eaten out of the home. Such developments provide opportunities for businesses to offer this higher quality and greater service element. Much of this higher value may be beyond the farm gate which signals to farmers and their cooperatives the direction they might develop to capture this activity. However, this point should not be overstated, even the highest quality animals raised in the most nurtured environments still only have one filet, one sirloin and a limited number of the other highest quality cuts. All animals have their lower valued quarters, cuts and offal. This meat will still be recovered and processed in the multitude of ways for burgers, kebabs, sausages, salamis, pies, convenience meals and for the catering trade.

In summary, producers remain to be convinced that radical change is required to move livestock into its safe operating space, however if consumption patterns start to change they will have little option but to respond. Then, apparatus of environmental policy and especially further renewed agricultural policy, together with publicly supported R&D, and innovation and technical assistance coming from input suppliers and the food industry can then help the primary production sector find its SOS.

5.4. International impacts of the EU moving into its SOS

The EU is a significant participant in international trade in livestock products, importing animal feed and exporting a mixture of animal products, some high value processed meat and dairy products and some lower value meat and animal products. Although the divergence between internal EU and world prices for agricultural products has narrowed since the mid-1990s, EU production is still protected by substantial tariffs for many livestock products: beef, dairy, pigmeat, poultry meat and eggs, and by some non-tariff measures[148]. EU farmers are also shielded by the generous payments under the CAP. Farmers' organisations defend the protection they receive on the basis that the EU has higher standards for health and hygiene, environment, animal health and welfare than in major exporting countries[149]. Despite this existing protection, a constant fear of producer interests when higher environmental or animal welfare standards are proposed is that this will impose additional costs and render domestic production less competitive with suppliers abroad. They claim raising standards will therefore hurt domestic producers and may displace local production in favour of imported goods produced to lower standards. This is often described as displacing and increasing pollution.

Given the complex array of policy levers required to move livestock into its SOS, and the difficulties of coordinating the quite different measures applied to consumers and producers, it is indeed quite likely that there will be different rates of progress on reducing consumption and reducing production especially for individual products amongst the wide array of livestock goods. Producers naturally fear that the measures addressed to them will have more immediate and greater effect inviting a surge of imports. For some products the opposite might happen and domestic consumption contracts more quickly or further than production, and the EU or a Member State may find its livestock product exports growing. This will invite criticism that the EU is suffering the pollution of other people's unsustainable consumption habits.

Three responses are offered to these concerns. The first, and the most important is that if it is the case that current livestock consumption/production levels are demonstrably unsustainable in the sense that they are approaching, at, or beyond boundaries which mean indefinite continuation of the activity is not possible, then corrective action is unavoidable. It is suggested that this *is* the current situation for livestock production. The difficulties are that neither consumers nor producers have yet been convinced their actions are unsustainable. Increasing numbers of consumers are becoming aware of the health and environmental concerns but these do not yet outweigh the immediate pleasure they get from consuming livestock products. For producers, the perceived short run impacts on their costs and profitability, and indeed the very survival of their business, outweighs fears of what seem diffuse and distant-in-space-and-time climate or environmental disasters that render their farm unmanageable. It has been argued that the prime initial task is to continue to accumulate the scientific evidence that livestock consumption and production *are* outside their safe operating space and to inform and educate consumers and producers about the consequences of inaction. Sooner or later this will create the social climate in which stronger actions can be introduced.

Second, is the need to debate these issues based on sound data assembled by trusted institutions under internationally agreed methodology. This is required to understand the relative efficiency and environmental impacts of each line of livestock production from countries around the world. Some will argue that markets, rather than researchers or civil servants, are by far the best mechanism for discovering where production is most efficient and least cost. In the absence of significant externalities or market imperfections this is indeed a sound answer. However, food production, and perhaps especially livestock production, is surrounded by significant external impacts on all environmental media, and to compound the complexity, there are strongly held ethical concerns about animal welfare. To make judgements on whether certain trade flows increase or diminish environmental damage globally requires scientific studies on impacts on each environmental medium of marginal changes in production, and for this to be available estimated on a comparable basis for the main trading countries across the world. This is a tall order.

Progress is being made on assembling comparable international data on some of the environmental impacts of production (Behrens et al., 2017). Such work has gone furthest on GHG impacts as there is an agreed basis for their measurement. There is much less progress when dealing with water quality and biodiversity. Even when comparable data can be assembled for each of these concerns there is a challenge of weighting and aggregating them and then embracing the animal welfare impacts of different livestock systems. For example, suppose the marginal impact of say the last 100,000 tonnes of production of

148 Two examples are that EU producers are prohibited from using hormones which increase growth rates and improve feed efficiency in beef production or somatotropins in milk production to increase milk yields in dairy cows, although imports are unaffected by this.

149 Claims are constantly made by producer organisations about the stringency, costs and strictness of implementation of regulation enforcing standards in these areas. There is little objective information documenting this.

South American and European beef could be measured for GHG emissions, water use, nutrient flows and thus water and air quality, and biodiversity. With such data, how could these effects be weighted and aggregated to judge for which of these two regions the overall net global social impact is lower? This would still leave assessment of animal welfare to be added to the judgement.

Such dilemmas are not likely to be resolved quickly, and they will certainly not be added into formal trading rules and disciplines in the foreseeable future. Setting legal standards is the task of political institutions. Through their procedures citizens express their priorities for regulation on nature protection, pollution and animal welfare, and decide how much assistance they are prepared to offer in subsidies and incentives to sectors which are forced to adjust. These can only be imposed on the local jurisdiction. Such decisions will have economic consequences, and through its willingness to generously fund the CAP the EU demonstrates it is prepared to provide the means to help farming sectors which have to adjust.

Third, for two of the most important environmental challenges, climate and biodiversity protection, there are in place international agreements (Paris 2015, and Nagoya 2010) in which signatories, which include most of the largest trading countries, have agreed to actions, respectively, to limit GHG emissions substantially, and to halt degradation and encourage restoration of biodiversity. Therefore, if the EU takes actions which turn out to reduce its own livestock output more than it reduces consumption, and if this results in expanded production and increased exports to the EU from some other part of the world then those countries will have to accommodate this in their own commitments under the Climate and Biodiversity agreements. This makes it unlikely that these exporting countries will expand their production. Dissatisfaction and distrust of this response is distrust of international agreements.

Final words. Technical and economic change in the last seven decades have dramatically reduced the real cost of food and enabled an expansion of consumption of all foods to the extent that populations are eating themselves into ill health by consuming way beyond dietary advice. The livestock component of this over-consumption demands priority attention because of the intrinsic inefficient and leaky nature of animal production which results in serious environmental damage. The concerns expressed should not be viewed as an attack on livestock, but an attack on the negative health and environmental impacts of over-consumption of their products.

A more positive and more confident observation is that as a highly developed bloc, with a strictly regulated and well-supported farm and food sector, the EU and its standards are internationally trusted. Chinese dairy and meat imports from the EU are partly motivated by the greater trust endowed in high quality EU products. EU regulations are emulated and matched by many other countries. ***Europe should be confident that if it takes the lead in defining and moving to a safe operating space for livestock this can help set the standards and procedures which others will follow.*** Such first mover advantage will itself provide opportunities as Europe develops the information, motivation, messages, technologies, and policies for more sustainable, balanced livestock consumption and production.

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APPENDIX 1

Average meat and milk consumption per capita per Member State and reductions required to reach the National Dietary Recommendations (for the methodology refer to section 3.2.1)

Member State	Meat	Milk	reduction in meat	reduction in milk
	kg/capita/yr	kg/capita/yr	%	%
Austria	55.8	216.1	-58.1	-6.3
Belgium	44.0	212.2	-46.8	-4.5
Bulgaria	33.8	130.0	-30.7	55.8
Croatia	39.7	197.7	-41.1	2.5
Czech Rep.	50.5	171.2	-53.6	18.3
Denmark	49.1	239.7	-52.3	-15.5
Estonia	42.2	229.3	-44.5	-11.6
Finland	46.4	353.2	-49.6	-42.6
France	55.8	218.7	-58.1	-7.4
Germany	53.2	232.1	-56.0	-12.7
Greece	48.3	253.8	-51.6	-20.2
Hungary	46.2	147.8	-49.3	37.1
Ireland	53.8	253.2	-56.5	-20.0
Italy	53.8	232.1	-56.5	-12.7
Latvia	41.5	188.4	-43.7	7.5
Lithuania	48.6	262.0	-51.8	-22.7
Luxembourg	62.1	227.1	-62.3	-10.8
Malta	52.7	161.7	-55.6	25.3
Netherlands	50.8	309.7	-53.9	-34.6
Poland	46.6	166.5	-49.8	21.7
Portugal	57.3	191.8	-59.1	5.6
Romania	36.1	225.9	-35.2	-10.3
Slovakia	35.8	117.8	-34.6	71.9
Slovenia	51.4	221.7	-54.5	-8.6
Spain	61.7	151.0	-62.1	34.2
Sweden	49.1	314.9	-52.3	-35.7
UK	50.8	214.7	-53.9	-5.6
Cyprus	49.3	114.9	-52.5	76.3
EU-28	51.5	213.8	-54.6	-5.2

APPENDIX 2

Current ruminant livestock units per Member State and reductions required to achieved the proposed scenarios (scenario 1: 0.5 LSU/ha and scenario 2: 1 LSU/ha). (for the methodology refer to section 3.2.2)

Member State	Current values	Scenario 1	Scenario 2	Scenario 1	Scenario 2
	million LSU	million LSU	million LSU	% of current	% of current
Austria	1.47	0.54	1.08	36.53	73.06
Belgium	1.83	0.24	0.48	13.23	26.46
Bulgaria	0.64	0.44	0.89	69.34	138.67
Croatia	0.39	0.20	0.39	49.86	99.71
Cyprus	0.10	0.00	0.00	0.70	1.40
Czech Republic	0.99	0.47	0.94	47.52	95.03
Denmark	1.16	0.06	0.12	5.07	10.14
Estonia	0.20	0.11	0.22	54.14	108.28
EU28	74.00	24.08	48.16	32.54	65.08
Finland	0.65	0.01	0.02	1.55	3.10
France	15.14	3.67	7.34	24.23	48.46
Germany	9.47	2.25	4.51	23.79	47.58
Greece	1.44	0.58	1.16	40.11	80.22
Hungary	0.72	0.19	0.38	25.96	51.91
Ireland	4.93	1.74	3.48	35.25	70.50
Italy	5.50	1.36	2.73	24.78	49.56
Latvia	0.32	0.19	0.37	57.56	115.12
Lithuania	0.56	0.25	0.49	43.82	87.64
Luxembourg	0.15	0.03	0.07	22.56	45.12
Netherlands	3.04	0.37	0.75	12.31	24.62
Poland	4.29	1.49	2.98	34.76	69.53
Portugal	1.38	0.59	1.17	42.54	85.08
Romania	2.57	1.93	3.86	75.10	150.21
Slovakia	0.40	0.24	0.48	60.06	120.12
Slovenia	0.33	0.13	0.25	37.96	75.91
Spain	5.90	2.66	5.32	45.04	90.08
Sweden	1.10	0.21	0.42	19.05	38.09
United Kingdom	9.33	4.14	8.29	44.41	88.81
EU28	74	24.07994	48.15987	32.54045	65.08091

APPENDIX 3

Change in GHG emissions in agriculture and livestock (direct emissions from livestock only) between 1990 and 2013 and required reductions to meet Paris Climate Agreement Goals (Data from the Eurostat database from EEA: 'Greenhouse gas emissions by source sector' [env_air_gge])

Member State	1990-2013 change in GHG			Required reductions to achieve Paris Climate Goals (-40%, -60%, -80%)		
	Agriculture	**Livestock**	**Livestock's contribution**	**2030 (-40%)**	**2040 (-60%)**	**2050 (-80%)**
	% change	**% change**	**%**	**%**	**%**	**%**
Austria	-13.8	-14.6	70.8	-29.8	-53.2	-76.6
Belgium	-19.1	-15.6	65.4	-28.9	-52.6	-76.3
Bulgaria	-54.7	-68.3	38.7	89.3	26.2	-36.9
Croatia	-37.2	-44.3	57.8	7.6	-28.2	-64.1
Cyprus	3.6	13.2	78.1	-47.0	-64.6	-82.3
Czech Rep.	-52.3	-54.7	55.6	32.4	-11.8	-55.9
Denmark	-18.6	-3.9	61.3	-37.6	-58.4	-79.2
Estonia	-51.2	-54.0	54.0	30.3	-13.1	-56.6
Finland	-13.8	-9.2	43.1	-33.9	-55.9	-78.0
France	-8.8	-9.4	54.2	-33.8	-55.8	-77.9
Germany	-18.0	-27.2	53.4	-17.6	-45.1	-72.5
Greece	-17.2	-3.6	58.9	-37.8	-58.5	-79.3
Hungary	-36.4	-48.3	47.5	16.0	-22.7	-61.3
Ireland	-6.1	-6.8	64.9	-35.6	-57.1	-78.5
Italy	-15.0	-15.0	62.7	-29.4	-52.9	-76.5
Latvia	-52.1	-62.5	39.7	59.9	6.6	-46.7
Lithuania	-50.8	-62.9	46.9	61.6	7.7	-46.1
Luxembourg	-7.9	-4.7	76.0	-37.0	-58.0	-79.0
Malta	-13.1	-17.1	69.6	-27.6	-51.8	-75.9
Netherlands	-27.1	-17.9	71.0	-26.9	-51.3	-75.6
Poland	-35.3	-41.6	51.6	2.7	-31.5	-65.8
Portugal	-7.3	-5.8	64.8	-36.3	-57.5	-78.8
Romania	-46.8	-48.5	69.2	16.5	-22.3	-61.2
Slovakia	-54.9	-63.4	44.7	64.0	9.3	-45.3
Slovenia	-13.5	-14.6	73.4	-29.7	-53.1	-76.6
Spain	-4.0	0.2	68.3	-40.1	-60.1	-80.0
Sweden	-9.4	-7.1	52.4	-35.4	-56.9	-78.5
United Kingdom	-17.6	-17.0	64.9	-27.7	-51.8	-75.9
EU28	-22.2	-23.9	58.9	-21.2	-47.4	-73.7

APPENDIX 4

Member State data on Gross Nutrient Balance (GNB), population and maximum estimated nitrogen fixation established by the nutrient boundary. The last column shows the percentual difference between total nitrogen fixation and the maximum N fixation established by the nutrient boundary and is the basis for Figure 12. Data are reported in Tn of nutrients. Reference year is 2013 (For more information refer to section 3.2.4. Metadata on Eurostat's GNB can be found here: http://ec.europa.eu/eurostat/cache/metadata/en/aei_pr_gnb_esms.htm)

Member State	Fertiliser input	Biological fixation	Total N fixation	Population	Max. N fixation	Total N – difference
	Tn	Tn	Tn	Number	Tn	%
Austria	112005	33750	145755	8451860	72686	50
Belgium	143615	9343	152958	11137974	95787	37
Bulgaria	258856	13468	272324	7284552	62647	77
Croatia	77920	11095	89015	4262140	36654	59
Cyprus	3147	204	3351	865878	7447	122
Czech Rep.	331616	33438	365054	10516125	90439	75
Denmark	193688	13605	207293	5602628	48183	77
Estonia	33659	6659	40318	1320174	11353	72
Finland	138136	4854	142990	5426674	46669	67
France	2143821	314317	2458138	65600350	564163	77
Germany	1648828	192400	1841228	80523746	692504	62
Greece	182534	11088	193622	11003615	94631	51
Hungary	342949	16223	359172	9908798	85216	76
Ireland	353044	34669	387713	4609779	39644	90
Italy	546542	311188	857730	59685227	513293	40
Latvia	69700	32532	102232	2023825	17405	83
Lithuania	154000	13947	167947	2971905	25558	85
Luxembourg	13944	1124	15068	537039	4619	69
Malta	636	0	636	422509	3634	471
Netherlands	216026	6859	222885	16779575	144304	35
Poland	1201967	56850	1258817	38062535	327338	74
Portugal	110643	32283	142926	10487289	90191	37
Romania	344468	106522	450990	20020074	172173	62
Slovakia	129860	35342	165202	5410836	46533	72
Slovenia	27263	2142	29405	2058821	17706	40
Spain	961451	168850	1130301	46727890	401860	64
Sweden	161100	34103	195203	9555893	82181	58
UK	999000	80544	1079544	63905297	549586	49
EU28	10900418	1577399	12477817	505163008	4344402	65

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