Towards the future production of animal-sourced food meeting food security, environmental and biodiversity objectives concomitantly

Simon Oosting[1], André Bannink[2], Camila Bonilla-Cedrez[1] , Sinead Leahy[3], Andreas Wilkes[3], Harry Clark[3]

[1] Animal Production Systems group, Wageningen University & Research. P.O. Box 338 6700 AH Wageningen, The Netherlands. simon.oosting@wur.nl

[2] Wageningen Livestock Research, Wageningen University & Research. P.O. Box 338 6700 AH Wageningen, The Netherlands

[3] New Zealand Agricultural Greenhouse Gas Research Centre, Tennant Drive, Private Bag 11008, Palmerston North 4442, New Zealand

Abstract

Production of animal-sourced food is important for human wellbeing by its contribution to food security and livelihood support. However, it is also associated with impacts on the environment and on biodiversity. The present research paper provides background information about the various objectives of animal-sourced food production. Various approaches to achieve sustainable livestock development are presented such as innovations with the present systems as an entry point vs systemic changes with a new basis for animal-sourced food production. Case studies from four continents (the beef and sheep sector in New Zealand, the dairy sector in the Netherlands, silvopastoral systems with beef production in Colombia, and dairy production in Kenya) are presented to illustrate the diversity in contexts, in interventions and in outcomes. Most interventions are technological and manegerial interventions that take the present situation as an entry point. All contribute to sustainable debvelopment, but some in some contexts outcomes are not meeting targets and more systemic changes are required. Adoption and implementation of interventions is essential for sustainable livestock development, and therefore the creation of an enabling environment in which farmers, value chain actors and policy makers collaborate, should be the key element of policies and projects towards a future production of animal-sourced food meeting food security, environmental and biodiversity objectives concomitantly.

1 Objectives of animal-sourced food production

1.1 Animal-sourced food production and human wellbeing

One important role of animal-sourced food (ASF) production for human wellbeing is the contribution to human food security. In high-income countries ASF consumption is often high and also for many people in low- and middle-income countries (LMICs) milk, fish, and eggs are frequent components of the daily diet. Meats, such as beef, pork, mutton, and poultry meat, are consumed less frequently in LMICs, e.g., only at festivities.

Rising incomes shift consumption from plant-sourced food to ASF. ASF has a high income elasticity of demand (International Food Policy Research Institute 2017), which implies that an increase in income brings about a considerable increase in demand (Speedy 2003). Human beings can exist when consuming minimal or none ASF, though balancing nutrient supply from these diets requires knowledge and access to a diverse food basket. Such requirements are not met for everybody, e.g., the poor. Hence, for sound nutritional reasons, many countries have included ASF in their National

Dietary Recommendations (NDRs; FAO 2018). These NDRs are country-specific dietary guidelines that address public health and nutrition priorities and accessibility of foods. Nutritional reasons to include ASF in NDRs encompass that ASF provide proteins with a high bioavailability and an amino acid profile meeting human requirements (Elmadfa and Meyer 2017). In addition, they are important sources of micronutrients such as calcium, iodine, zinc, selenium, iron, vitamins A, B12, D and folic acid (Beal et al. 2021; Biesalski 2005), specifically for the world's poor (Adesogan et al. 2020).

Besides its contribution to food security, livestock has many roles and functions in the livelihood of farming families: they have cultural and societal functions such as for dowry and sacrifices during religious festivities; they have financial and insurance functions which are specifically important to the poor; they may provide regular small income to women and children in a household, and they may provide status. Such livelihood functions of livestock are most important in subsistence farming systems (Moll et al. 2007; Oosting et al. 2014; Rao et al. 2021; Udo et al. 2011).

1.2 Impacts of animal-sourced food production

ASF production is associated with three major environmental impacts: (1) climate change, (2) nitrogen (N) and phosphorus (P) losses to the environment, and (3) biodiversity loss. Mitigating these impacts while continuing to contribute to food security presents major challenges.

(1)Climate change

ASF production contributes to climate change by emitting greenhouse gases (GHG). There are four major sources of GHG emissions from livestock (Gerber et al. 2013):

a) Enteric fermentation during digestion of feeds in rumen and hindgut of ruminants. In this process methane is emitted.
b) Manure deposition, collection, storage, handling, and application during which methane and nitrous oxide are emitted.
c) Cultivation, production, processing, and transport of animal feed during which nitrous oxide from fertilization and carbon dioxide from combustion of fossil fuels are emitted.
d) Land use change, for example when natural vegetation, such as forest, is being turned into grassland or cropland to produce feed crops. Natural vegetation and the soils it grows on often contain much greater carbon stocks than agricultural soils. The loss of organic matter during the transition of land use causes mainly carbon dioxide emissions but can also leads to new emissions of nitrous oxide and methane.

GHG-emissions are often summed based on their global warming potential (GWP) expressed in carbon dioxide equivalents (CO_2-e, 1 unit non-fossil methane counts for 27.2 units CO_2-e and 1 unit nitrous oxide counts for 273 units CO_2-e; (GWP100, IPCC AR6) and presented per kg of product, per unit of food energy or (as in Table 1) per 100 g of food protein, being referred to as the emission intensity of that product or item. The GHG emissions associated with ASF production depend on the farming system and the farmed animal species. Table 1 compares GHG emissions associated with ASF and some plant sourced foods. These are derived from a meta-analysis of published life cycle assessment studies of agricultural production by Poore and Nemecek (2018). Ruminant meat production has the highest mean GHG emission intensities, followed by milk production (represented by cheese in Table 1), fish, pig and poultry production. All ASFs in Table 1 have higher GHG emission intensities than the plant-sourced food products. The variation in emission intensities of ASF (for which the difference between the mean and the 10^{th} percentile (the value below which 10 % of the observations are found) is used as a proxy) is high, indicating that there are farms producing low- and farms producing high-GHG emission intensity products. This implies that there is room for GHG emission mitigation, particularly through improvements on farms producing high GHG emission intensity products. One important determinant of GHG emission intensities within an ASF product is the production per animal. A high production per animal implies that the emissions associated with the animal's maintenance are diluted across many liters or kilos of produce (Gerber et al. 2011), and that the quality of the ingested feed is relatively high which is associated with relatively low emissions per unit of this ingested feed.

ASF production is a significant contributor to climate change (14.5 % of all anthropogenic GHG-emissions) and there is a need to mitigate this. Simultaneously, there is need for ASF production to adapt to climate change. Reduced feed availability and quality, as a consequence of changing patterns of rainfall, and generally increased ambient temperatures are examples of climate change effects which have important impacts on ASF production (Thornton et al. 2021) and farming systems will have to adapt or transform to cope with these impacts.

Table 1 Greenhouse gas emissions and land use associated with production of protein rich foods (Source: Poore and Nemecek 2018, adapted by Oosting et al. 2021)

Protein rich foods	Greenhouse gas emissions (kg CO_2-e 100 g protein^{-1})		Land use (m^2 100 g protein^{-1})	
	Average	10^{th} percentile	Average	10^{th} percentile
Animal-sourced Foods				
Beef	50	20	164	42
Lamb & mutton	20	12	185	30
Cheese	11	5.1	41	4.4
Pig meat	7.6	4.6	11	4.8
Fish (farmed)	6.0	2.5	3.7	0.4
Poultry meat	5.7	2.4	7.1	3.8
Eggs	4.2	2.6	5.7	4.0
Plant-sourced Foods				
Tofu	2.0	1.0	2.2	1.1
Groundnuts	1.2	0.6	3.5	1.8
Peas	0.4	0.3	3.4	1.2
Nuts	0.3	-2.2	7.9	2.7
Grains	2.7	1.0	4.6	1.7

(2)Losses of nitrogen and phosphorus to the environment

Most losses of N and P from livestock production to the environment are either associated with animal manure management or with the fertilization of crops and grasslands for feed production (Mu et al.

2016). N and P are important nutrients for crops, grassland, and livestock. In farming systems, N and P flow from soils to crops and grass, then to livestock via feed, and then again to the soil via manure. Farms may import N through fertilizers, feed, deposition, and fixation by plants and P through fertilizers and feed. Farms usually export N and P through products. If imports are higher than exports, a farming system has a nutrient surplus. The higher the nutrient surplus, the higher the risk of losses of nutrients to the environment. Substantial losses cause i) eutrophication of terrestrial and aquatic ecosystems resulting in excessive growth of, e.g., algae that grow on the nutrients and ii) acidification of the environment (acidic compounds in rain and soils). Eutrophication has important consequences for biodiversity and may even lead to "dead zones" in water bodies and acidification of the environment affects vegetation (e.g., forests) and aquatic life. High intensity ASF production is often associated with high imports of nutrients and consequently risks high N and P losses to the environment. These are difficult to prevent, particularly the loss of volatile N sources.

(3) Impacts on biodiversity

ASF production uses land and water sources; many ruminant animals graze outdoors and a large land area is used to produce animal feed. It is estimated that 40 % of global habitable land is being used for feed production (Van Zanten et al. 2019). Land use differs between animal species as shown in Table 1. Land use (unit of land used per unit of ASF) is higher for ruminant ASF than for all plant-sourced foods, whereas the land used for fish-, pig-, and poultry-sourced foods is similar to those of plant-sourced foods with the highest land use. Land and water use impact biodiversity along the following pathways:

a) Forests and other natural vegetation are cleared and converted to land to cultivate feed crops and pasture. Such land use changes result in the release of GHG, and they negatively affect the local biodiversity.
b) Ruminant production can cause land degradation**.** If grassland use for ruminant production is mismanaged, overgrazing and soil-mining may occur, which can cause degradation, affecting vegetation cover (e.g., reducing it, changing it from grass to shrub, or even entirely eliminating it) and potentially resulting in productivity losses, soil erosion, soil carbon losses, and adverse impacts on biodiversity and water cycles (Garnett et al. 2017).
c) Livestock production and ASF processing may impact water and land resources through pollution. N and P may cause this pollution, but also pesticides and chemicals. Losses eventually migrate into ecosystems through the food chain and through water flows affecting the fauna and flora, as well as fisheries, recreation, tourism, and drinking water.

It is, however, important to recognize that ruminant meat and milk are often produced on lands unsuited for crop production, and extensive forms of ruminant production exist that contribute to biodiversity and deliver ecosystem services (Kok et al. 2020). Intensive fish, pig, dairy, and poultry production require relatively high quality feeds grown on crop lands with usually intensive production practices (Oosting et al. 2021) with risk of negative effects on biodiversity.

2 Policies for future ASF production

In policy making and project formulation for ASF production development, there is increasing intention and desire to address environmental and biodiversity impacts. However, combining multiple objectives in policies and projects is difficult because of the complexity and the stationary nature of existing socio-economic and agricultural structures. The following approaches can be identified:

1) *Approaches with the present situation as the entry point:* An example is sustainable intensification (which is the increase of yields on current agricultural land without adverse environmental impacts (Garnett and Godfray 2012), based on technological innovations such as improved feed and feeding management (including the use of feed additives), and breeding to increase livestock productivity which reduces GHG emission intensities. If the feeding and breeding improvement is combined with advanced manure management, N and P losses to the environment can be minimized.

2) *Approaches with a future, desired image as entry point:* One example is the exploration of circular food systems which maximally use waste streams. Interventions aimed at maximal use of manure for fertilization and of agro-industrial waste streams for livestock nutrition may result in reduced N and P losses to the environment. The ultimate consequence of circularity of food systems is that the output of ASF per capita has to reduce in temperate climate regions, whereas only limited increase can be achieved in tropical regions (Oosting et al. 2021).

3) *Approaches combining 1) and 2) making best use of what both approaches may offer.* An example of this is the World Bank project https://www.sustainablelivestockguide.org (World Bank 2019) which addresses the complexity of combining livestock production objectives and environmental objectives. Through such an approach relatively simple principles can be proposed which contribute to livestock production and environmental objectives. The principles are based on lessons learned from livestock development projects. They can be applied in the following manner:

Principle 1. Contribute to a sustainable food future.

Before a policy is made or a project is formulated the comparative advantage of livestock production over other activities that could meet the policy or project objectives should be evaluated.

Principle 2. Enhance carbon stocks.

Livestock development presents an opportunity to protect and enhance carbon stocks for example by restoring degraded grassland, and by (partial) reforestation in silvo-pastoral systems.

Principle 3. Improve efficiency at animal and herd level.

Where yields of livestock are low, productivity should be increased and growth in animal numbers should be avoided

Principle 4. Source feed sustainably.

Livestock development often requires use of feeds with high nutritional quality. Whether grown on-farm or sourced elsewhere, such high-quality feeds should be produced with low impact on the environment.

Principle 5. Couple livestock to land.

Intensification of livestock production may result in import of feed and fertilizers and lead to high surpluses of N and P per ha. N and P surpluses should be applied to land as fertilizer which requires proper manure management (storage, treatment, transportation, and application) to minimize losses of N and P.

Principle 6. Minimize fossil fuel use.

Livestock development presents opportunities to invest in energy-efficient technologies and renewable energy generation along the value chain.

Principle 7. Foster an enabling environment.

Enabling institutions, policies, knowledge, and awareness are necessary for achieving principles 1 through 6.

The choice between approaches depends on the time horizon allowed and required to reach the policy or project objectives. Usually, the political, and socio-economic reality is such that policies and projects have a limited time horizon and approach 1 is often followed. Meta-analyses done by the Feed and Nutrition Network of the Global Research Alliance on Agricultural Greenhouse Gases (FACCE-JPI Global Network project; De Souza-Congio et al. 2021) show that this approach may be effective to reach improvements in the order of 10 to 30%. However, global problems such as climate change and biodiversity loss require a long time horizon for mitigation and systemic changes are required. Approach 2 and combination of approaches 1 and 2 are probably needed to really achieve solutions for such global problems.

Conditional aspects and constraints

To have successful policies and projects aimed at a future production of ASF meeting food security, environmental and biodiversity objectives, implementation and adoption are crucial. Support of actors, such as farmers and processors is crucial for implementation. The following list gives some aspects and constraints which should be considered in policy making and project formulation.

- Economic feasibility of livestock farming and processing is crucial to sustain investments in production.
- Existing infrastructure and traditions may be serious constraints for change (e.g., the well-known example of cattle in tropical systems that have a role as draught animals or to serve as a store of capital: rationalising on milk production in such systems will inevitably lead to reduction of such roles for cattle and imply a reduced livelihood security for the farming family. This may be a constraint to adoption (Oosting et al. 2014)). Moreover, existing regulations, trade agreements, subsidies, taxes, and import/export conditions also determine the feasibility of scenarios for future livestock production.
- Climatic events may affect the extent to which farmers are willing to take risks and may hamper future investments.
- Climate change may already force farmers to adapt or transform their farming systems making desired pathways for change less applicable.
- Demographic and associated market developments may impact feasibility of development policies and projects.
- Positive contributions of livestock production may be overlooked. Livestock may give resilience to food systems. It may, for example, act as a food-providing buffer in harsh periods when crop yields are low due to droughts or pests. It may be an important income source for women. Moreover, it is a means to convert non-edible by-products, biomass and food wastes into ASF.

3 Case studies: interventions contributing to food security, environmental impact mitigation and prevention of biodiversity loss

The present research paper will present four case studies of interventions with contributions to food security, environmental impact mitigation, and prevention of biodiversity loss. Case studies from four continents have been chosen, to illustrate the diversity in contexts and farming systems, in approaches and interventions implemented and in extent to which outcomes were meeting the desired effects. The following case studies will be presented:

1) The sheep and beef sector in New Zealand
2) Dairy production, nutrient use efficiency, and circular economy in the Netherlands
3) Beef production in silvopastoral systems in Colombia
4) A tier 2 inventory system for dairy production in Kenya

3.1 The sheep and beef sector in New Zealand

Agriculture makes a significant contribution to the New Zealand economy, and has helped to shape its landscapes, communities, and culture. The total land area of New Zealand is 26.8 million hectares with almost 40%, about ten million hectares, being used for pastoral agriculture – predominantly dairy, sheep, and beef farms. In 2019, 48% of New Zealand's reported total GHG emissions were from the agricultural sector, with farming of ruminant livestock the main contributor. There are currently about 26.8 million sheep and 3.9 million beef cattle in New Zealand and the sheep and beef sector accounts for approximately 42% of reported agricultural emissions. New Zealand's sheep and beef sector is world leading in its approach of empowering farmers to understand, measure and mitigate impacts on the environment, including greenhouse gas emissions, biodiversity, water quality and soil health.

Efficiency improvement and value adding

The profile of agricultural emissions from the sheep and beef sector has transformed in the past 30 years. Agricultural subsidies were completely removed in the 1980's and farmers adapted quickly by becoming more efficient producers. Marginal land has been retired and returned to a natural state and production has been focussed on areas where it makes sense to do so. Since 1990, sheep numbers have more than halved, while production has only fallen by a small amount and export values have more than doubled (Figure 1).

This has delivered significant improvements in the sector's environmental footprint. It is a story of improved efficiencies, value adding and economic gain. On-farm efficiencies increased through interventions such as better feed and feeding management and genetic improvements, whereas value addition was achieved through processing innovations.

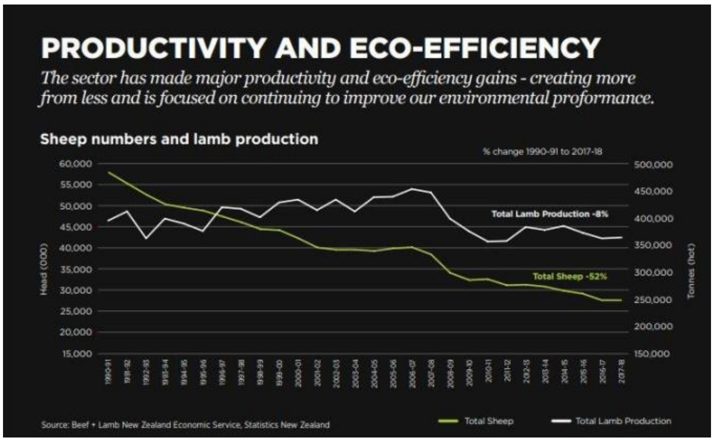

Figure 1. Sheep herd size and productivity in New Zealand (Source: Beef and Lamb New Zealand 2020 and Ministry for the Environment 2020a)

Table 2 shows the increased in sheep and beef performance indicators from 1990/1991 to 2019/2020. Lambing rate (number of lambs born per ewe), lamb carcass weight and consequently the meat production per ewe have increased considerably during this period. This has led to significant efficiency gains and supported reductions in GHG emissions from sheep. Output per head in the beef sector increased slightly from 1990/1991 till 2019/2020.

Table 2. Sheep and beef production indicators in New Zealand

Indicator	**1990/1991**	**2019/2020**	**Change (%)**
Sheep			
Lambing rate (# lambs 100 ewes^{-1} year^{-1})	102	129	+27
Carcass weight at slaughter (kg head^{-1})	13.9	19.0	+37
Productivity (kg meat ewe^{-1})	9.8	21.5	+120
Beef			
Body weight (kg head^{-1} year^{-1})	297	312	+5

(Source: Beef and Lamb New Zealand 2021)

Since 1990 GHG emissions from the sheep sector have reduced by 41% (see Table 3) and the emission intensity of sheep production has reduced (estimated by on-farm Life Cycle Analysis) and it is around half the average figure globally. The emission intensity of the beef sector has decreased by 8 % since 1990. The emission intensity of meat production is lower for beef than for sheep meat.

Table 3. Sheep and beef greenhouse gas emission indicators in New Zealand

Indicator	1990	2019	Change (%)
Sheep			
Total greenhouse gas emissions ($kT\ CO_2$-e year^{-1})	14558	8527	-41
Greenhouse gas emission intensity (kg CO_2-e kg meat^{-1})	27.5	18.9	-31
Beef			
Total greenhouse gas emissions ($kT\ CO_2$-e year^{-1})	5950	5894	-1
Greenhouse gas emission intensity (kg CO_2-e kg meat^{-1})	13.9	12.8	-8

(Source: Ministry for the Environment 2020a and Beef and Lamb New Zealand 2021)

There is significant sequestration happening on New Zealand sheep and beef farms. A New Zealand Government report (Ministry for the Environment 2020b) found that New Zealand sheep and beef farms were sequestering around 33 percent of on farm agricultural emissions through woody vegetation and drained organic soils (Figure 2).

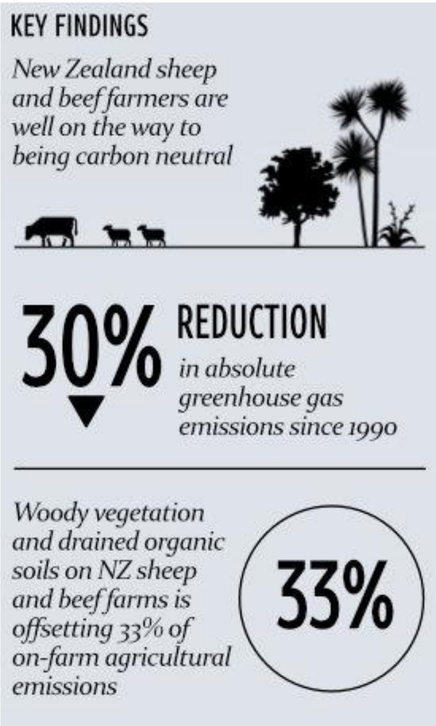

Figure 2. Key findings New Zealand sheep and beef sector contributions to climate change mitigation

Biodiversity & Water

Since 1990, the land used for sheep and beef production in New Zealand has decreased by 4.3 million ha from 12.5 million ha to 8.2 million hectares. Sheep and beef farming has not, however, become any more intensive: stocking rates (the number of animals per hectare) have remained similar over this time. A portion of that land-use change has gone into forestry which reduces losses due to erosion and can provide valuable habitat for some native species. It is estimated that 24% of all New Zealand's remaining native vegetation cover, including both native grasslands and native forest is on sheep and beef farms. Beef and sheep farmers are actively working with each other and their local communities to better manage freshwater via catchment groups.

Investment in further reducing emissions

Significant work has been undertaken in New Zealand to develop innovative mitigation technologies to reduce biological emissions from agricultural sources. Sheep and beef farmers have directly contributed to this research effort and since 2004 have invested in the Pastoral Greenhouse Gas Research Consortium, a joint industry and government partnership which, alongside the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) has pioneered the development of low methane emitting sheep.

Moreover, there is the *He Waka Eke Noa* – Primary Sector Climate Action Partnership. *He Waka Eke Noa* is a Māori phrase translated as 'we are all in this boat together', and it brings together food producers, government and Māori (indigenous people of New Zealand). The aim of He Waka Eke Noa is to build a system for farmers and growers to report their GHG emissions by 2024, have a plan to manage greenhouse gas emissions and adapt to a changing climate by 2025, and be incentivised to act on emissions through an appropriate pricing system in 2025.

The New Zealand Government decided to work with the sector to establish a system for pricing emissions because this approach recognises that different farm types will address emissions in different ways and allows for flexibility in approaches. Working in Partnership with the sector and Māori ensures that farmers are able to act on emissions by equipping them with the tools to do so. This also lets farmers incorporate GHG management into a whole of farm approach along with biodiversity, water quality, and animal welfare.

3.2 Dairy production, nutrient losses to the environment, alternative farming strategies, and circular food system in the Netherlands

The dairy sector in the Netherlands and nutrient losses to the environment

After the second world war, there was a strong incentive within the Netherlands as part of the European Union to assure food production, which implied intensification and scale enlargement of agriculture including dairy farming, a process that is still ongoing to date. Cattle breeding programs, improvement of on-farm feed production and conservation, and of farm management were achieved through mechanisation, intensive monitoring, a well-organized agricultural knowledge system, water management, and restructuring and reallocating of agricultural land. Dairy farms in the Netherlands today have on average 105 cows on 58.1 ha, a milk production of 9400 kg per cow per lactation and producing 17940 kg of milk per ha. Such modern dairy farms, however, have substantial import of feeds and artificial fertilizer, and apply high amounts of manure. Losses of N and P to the environment can be high. The effects of N and P losses to the environment are eutrophication and acidification (see introduction), and ammonia deposition from farms in the neighbourhood of nature areas result in enrichment of soils and disturbance of ecosystems. Therefore, stringent EU and national policies and legislation have been developed to prevent such losses (i.e. quota for milk production (EU, 1984-2015), restriction of manure application to the growing season (NL, 1987), low-emission practices for manure application (i.e., injection; NL, 1994), the EU nitrate directive (EU, 1991), a mineral accountancy system (NL, 1993) which was rejected by the EU and replaced in 2006 with the current system of manure and fertilizer application standards, the EU water directive (EU, 2000), and manure phosphate production rights (NL, 2018)). This successfully reduced the very large surpluses of N and P by tens of percentages. From 1990 till 2018, national ammonia emissions reduced from 169 to 64 kT per year, and specifically the ammonia emissions associated with manure application reduced considerably. These developments are indicated in Figure 3 by the trend of declining N and P surpluses since 1970 with that of P almost disappearing and that of N being halved since 1990. The GHG emissions from dairy declined per kg of milk (-18%) and per kg of feed (-3 %) in the first decade since 1990 (Bannink et al. 2018). However, reductions after 2000 were limited.

Despite the efforts and achievements made by the sector, it remains the main source of ammonia emissions and GHG emissions in the Dutch agriculture and further reductions targets have been set. This puts new and major challenges to the highly intensified Dutch dairy sector. Additional and new nutritional measures may help in reaching these targets as they have not been fully adopted so far, and boundaries may be set to the size and level of intensity of dairy farming practices near vulnerable natural areas.

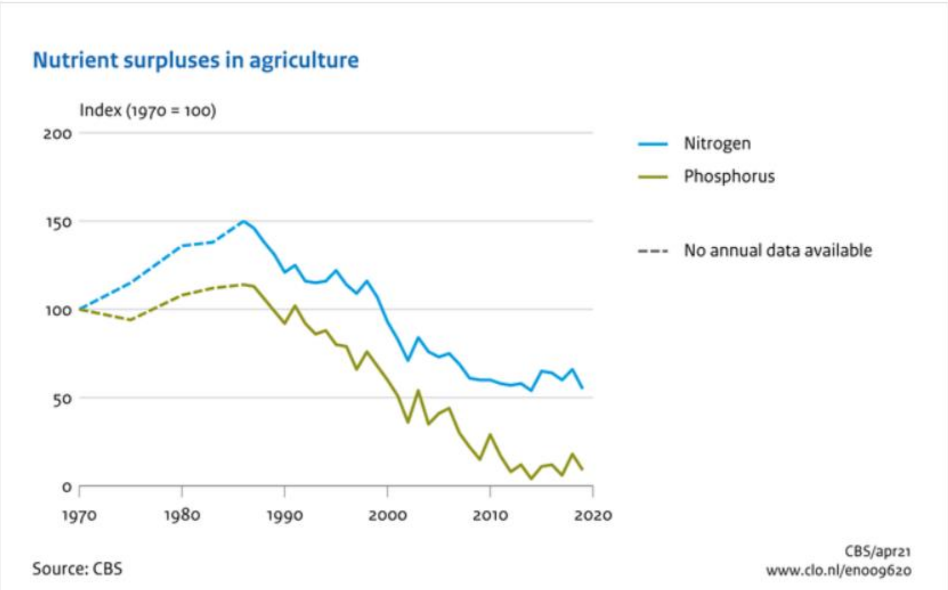

Figure 3. Nutrient surpluses in Dutch Agriculture (Source CBS 2021)

Alternative livestock farming strategies

Relatively high production costs and low milk prices have been important drivers of the scale enlargement and intensification in dairy farming in the Netherlands. Van der Ploeg and Roep (2003) presented in their framework for farming system development alternatives for scale enlargement and intensification namely deepening and broadening. Deepening is the transformation of agricultural production in order to get more added value per unit product. Examples of deepening are organic farming, production of high value products (farm cheeses) and sale to consumers via short chains. Broadening entails the inclusion of farm related activities such as agri-tourism, green care farming, nature management, or energy production. If farmers follow such strategies, they may get similar income with lower land use intensity and consequently less GHG emissions, N and P losses to the environment and more biodiversity per farm. An example is a collaboration between the 7 dairy farmers on the small island Schiermonnikoog in the North of the Netherlands. They developed recipes for new cheeses which are being produced by dairy processors from milk produced on the island and marketed under the name "van Schier". The farmers expect to get a premium of 10 euro cents per kg milk, and they engage in schemes for ecosystem services (e.g. protection of meadow birds). So they will maintain a farm income, while reducing the amount of milk produced on the island from 5 million (from a total of 606 cows) to 3 million kg (from a total of 375 cows) annually. There are plans to establish a cheese production unit at one of the farms. By having less cows and a relatively extensive production, the farmers of Schiermonnikoog realize less N deposition on the nature of the island, with positive effects on desired biodiversity.

Circularity of the food system

Recently, circularity has come to the fore as an integrated approach to develop food system sustainably. Circular food systems have four important cornerstones: they 1) use arable land and water bodies primarily to produce food for direct human consumption, 2) avoid or minimize food losses and wastes, 3) recycle by-products (such as crop residues, co-products from processing, manure, excreta), inevitable food losses, and waste streams back into the food system, and 4) use animals to unlock biomass with low opportunity costs for humans into value-food, manure, and ecosystem services. As a result, circular food systems apply practices and technologies that minimize the input of finite resources (e.g., phosphate rock, fossil fuel, and land), encourage the use of regenerative ones (e.g., wind and solar energy), prevent leakage of natural resources from the food system (e.g., of N and P), and stimulate recycling of inevitable resource losses in a way that adds the highest value to the food system (De Boer & van Ittersum 2018).

Livestock plays a role in circular food systems: waste stream biomass can be used as feed, and farmed animals provide manure which can be used as fertilizer to maintain or improve soil quality. The use of waste streams for feed may reduce the need for feed production with associated GHG emissions, land and water use, and N and P losses to the environment. Maximization of the use of manure for fertilization may prevent losses of these nutrients. Figure 4 illustrates the flow of biomass in a circular food system.

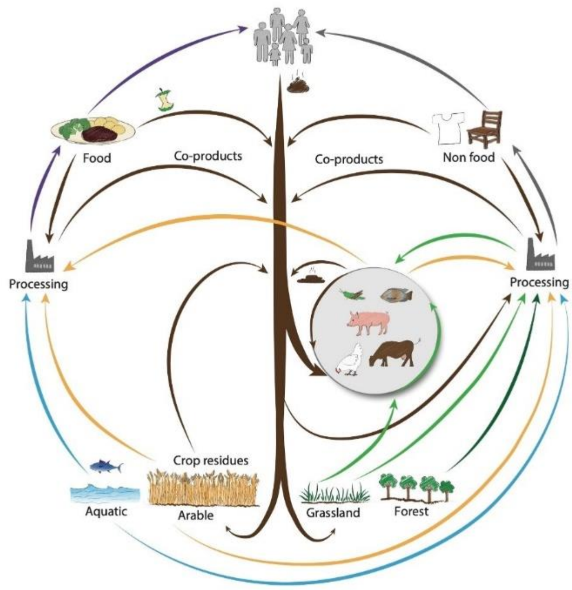

Figure 4. Flow of biomass in a circular food system (Muscat 2021)

Studies by Van Hal (2020), Van Kernebeek et al. (2014), and Van Zanten et al. (2019), indicate that protein consumption from ASF could be maintained at levels between seven and 36 g per capita per day, if livestock and fish would only consume feeds from waste streams and from lands (and water bodies) unsuited for human food crop production. In the Netherlands, present protein consumption from ASF is close to 60 g per capita per day. Circular food systems will therefore imply reduced ASF consumption in the Netherlands (and in other developed countries), which complies with dietary adjustments proposed to achieve healthy diets in the EAT-Lancet report (Willett et al. 2019). The Dutch Ministry of Agriculture, Nature and Food Quality is developing and implementing policies to increase circularity of land use in the Netherlands. Dairy production has an important role in this, as a land use activity on lands that cannot be used for crop production and as a converter of many by-product streams.

3.3 Beef production in silvopastoral systems in Colombia

Cattle production in Colombia

In Colombia, livestock contributes to 21.8% of the agricultural gross national product and generates income for more than half a million rural families (FEDEGRAN 2018). With 23.4 million head of cattle (ICA, 2017), beef production is to a major extend done on cattle farms with extensive pasture management. Grassland used by such farms cover more than 30 % of the country's land area (~ 24 Mha) (DANE, 2014; Landholm et al. 2019) and land conversion to pasture to increase farm production drives deforestation (Graesser et al. 2015). On farms, cattle are managed in large-sized paddocks with a low average stocking rate of 0.6 animals ha^{-1} (Teutscherova et al. 2021) and an average production of 225 kg $animal^{-1}$ (carcass weight) (FAO, 2019). Extensive pasture management, seasonal precipitation, and high temperatures lead to feed availability and quality limitations for livestock production (Ramirez et al. 2006), which in turn lead to high GHG emission intensities for the ASF from such farms. Moreover, overgrazing and soil compaction in pastures, e.g., in the Caribbean region of Colombia, resulted in degraded grassland prevalence of 80-100% associated with low availability and quality of the forage produced and low livestock production articulated in weight gains of less than 300 g animal^{-1} day^{-1} (Bellido et al. 2001; Quero et al. 2007; Martinez et al. 2014).

Silvopastoral systems as a mitigation option

Silvopastoral systems (SPSs) are proposed as a sustainable alternative to the conventional farming systems. Such SPSs introduce diversity and good practices that increase the quality of soils and grasslands, improve the productivity of the farming systems, and have the potential to reduce deforestation (Somarriba et al. 2012; Tapia-Coral et al. 2005). SPSs are a type of agroforestry where a production unit combines cattle, fodder plants (native or introduced grasses and legumes), and trees and shrubs (native, or introduced trees or legumes) for animal nutrition and complementary uses such as for windbreaks, shade, timber, and fruit production (Murgueitio et al. 2011; Chara et al. 2019). They have been implemented in several regions ranging in altitude from lowland (Caribbean and Orinoco region), to mid elevation (coffee growing region), and high altitude (Andean region up to 3000 masl), with variable annual rainfall (Murgueitio et al. 2011) and they enhanced livestock productivity up to four times in relation to traditional extensive systems (Murgueitio et al. 2011, Montagnini et al. 2013). Compared to the conventional system, SPSs have a high forage production that improves the availability and quality of the cattle diet (Yamamoto et al. 2007; Dagang and Nair 2003) and increases the productivity of the system (Table 4).

Table 4. Beef production in three tropical beef production systems in Colombia. (Adapted from Murgueitio et al. 2014)

Parameter	**Extensive conventional grazing systems**	**Improved grazing systems without trees**	**Intensive silvopoastoral systems**
Stocking rates (animals ha^{-1})	0.5	1	3
Daily gain (kg animal^{-1} d^{-1})	0.37	0.5	0.75
Daily gain (kg ha^{-1} d^{-1})	0.185	0.5	2.25
Days to slaughter (250-440 kg)	514	380	253
Productivity (kg of beef ha^{-1} year^{-1})	67.5	182.5	821.3
Land use (ha ton of beef^{-1})	14.8	5.5	1.2

SPSs are explicitly mentioned in Colombia's Nationally Determined Contributions and are becoming the technology of choice for the Colombian livestock sector to mitigate and adapt to climate change. The cattle productivity increase reduces the GHG emission intensity of the products (Chara et al. 2009), but research in Colombia, Nicaragua, and Costa Rica also showed that SPSs have more carbon in aboveground biomass and in soils than degraded pastures, whereas timber production also contributes to carbon sequestration. Martinez et al. (2014) demonstrated that, even with moderate tree planting densities, the implementation of SPSs reduced GHG emissions by 2.6 t CO_2-e ha^{-1} year^{-1} in comparison to current practices in Colombia.

SPSs also offer environmental services such as the recovery of degraded areas (Murgueitio et al. 2011; Martinez et al. 2014), articulated in reduced erosion, better nutrient cycling, more water infiltration, improved below-ground and above-ground biodiversity (Schultze-Kraft et al. 2018). Management such as pruning could contribute to 5-6 t ha^{-1} year^{-1} of residues that will become soil organic matter (Murgueitio et al. 2007). The incorporation of leguminous species such as *Leucaena leucocephala* or fodder banks with legumes, enhance symbiotic nitrogen soil fixation (from 52 to 400 kg N ha^{-1} $year^{-1}$) (Cubillos et al. 2016; Murgueitio et al. 2007). Intensive rotational grazing management practices in SPSs result in better use of forage species and the development of denser sprouts (Senra et al. 2005).

Animal welfare improves because the incorporation of shrubs and trees reduces air (2-3 °C) and soil surface (as much as 13 °C) temperature (Murgueitio et al. 2014; Cubillos et al. 2016). Shade of the trees reduced cattle skin temperatures up to 4 °C, less sun exposure reduces sunburn, cancer, and photosensitisation (Rowe 1989). Increase in biodiversity and predators lowers the populations of ticks, injurious insects, and the incidence of diseases such as anaplasmosis (from 25 to <5%) which leads to a reduction of antibiotic use (Murgueitio and Giraldo 2009).

In short, the introduction of SPS is a combination of better practices and introduction of diversity into beef production systems. One could argue that intensive grassland cultivation alone, with optimal management, could potentially prevent soil degradation and result in high forage availability and quality and high cattle productivity. However, SPSs often operate at a lower input level than intensified systems and have a high resilience because of the diversity in the system. In addition, SPSs provide ecosystem services, and be more independent in the use of external agricultural inputs such as inorganic fertilizer and concentrates.

3.4 A tier 2 inventory system for the Kenyan dairy sector

Dairy in Kenya and GHG inventory

Kenya is Africa's second largest milk producer, with about 4.6 million dairy cattle. Most of the milk is produced on smallholder farms, and milk sales contribute significantly to farmers' incomes, food and nutrition security, as well as employment in the formal and informal dairy sectors. However, dairy cattle contribute about 8% of national GHG emissions, and emissions continue to increase from the growing dairy herd. Recognizing the potential to attract climate finance and private sector investment in dairy development, Kenya's State Department for Livestock began to develop a Nationally Appropriate Mitigation Action (NAMA) for the dairy industry. A core component of the NAMA aims to reduce GHG emissions per unit of milk by increasing productivity.

For policy making and project formulation knowledge of GHG emissions and cattle productivity is important. The Intergovernmental Panel on Climate change (IPCC) has developed different approaches to estimate GHG emissions. The Tier 1 method relies on default emission factors per animal (cow for dairy production). So this Tier 1 approach can only reflect differences in size of cattle population. The Tier 2 method can reflect differences in productivity. This Tier 2 approach was therefore included in a GHG quantification methodology developed for the Dairy NAMA. It soon became apparent, however, that if the inventory used a Tier 1 method and the NAMA measurement, reporting and verification (MRV) system used a Tier 2 method, the emissions and emission reductions reported by each part of the MRV system would be incompatible with each other. Also, Kenya's first NDC was based on emission scenarios made using the inventory's Tier 1 method, and the GHG effects of changes in dairy productivity could not therefore be reflected in the NDC scenarios or targets. Adopting a Tier 2 methodology in the national inventory was thus seen as a key step to link project-level initiatives with national MRV systems for coherent GHG reporting. In addition, having such system in place facilitates targeted policy making for climate change mitigation policies.

The compilation of the Tier 2 inventory

Since the main motivation for developing a Tier 2 inventory arose from the livestock sub-sector, the State Department for Livestock took the initiative to consult with stakeholders on the need for a Tier 2 inventory:

-In January 2018, the State Department for Livestock, with support from the Food and Agriculture Organisation of the United Nations and the Global Research Alliance on Agricultural Greenhouse Gases, convened a meeting to raise awareness and gain consensus on the decision to compile a Tier 2 inventory. Participants from national agencies mandated with environmental and statistical matters and dairy industry stakeholders agreed on the necessity to adopt a Tier 2 method for dairy cattle in the GHG inventory.

-In June 2018, a further workshop was convened, attended by representatives of the Climate Change Directorate of the Ministry of Environment and Forestry, which has overall responsibility for the national GHG inventory, other government agencies and dairy industry technical specialists. The workshop provided training in the technical requirements for a Tier 2 inventory, outlined options for the overall structure for the inventory, and identified potential sources of data. Workshop participants produced an action plan for compiling the inventory and agreed to involve dairy specialists and inventory experts in an inventory 'core team'.

With support from UNIQUE forestry and land use, a consulting firm, the State Department for Livestock assessed data availability and other challenges, and core team members were consulted on alternative data sources, assumptions and methods (Unique 2020). Key challenges included, for example, how to estimate cattle population in different production systems when national data only reported total populations, and how to estimate trends in milk yield when national data uses fixed technical coefficients for milk yield per cow. Solutions suited to national conditions – including data availability constraints – were agreed.

The inventory was compiled using the best available data and methods that comply with IPCC Guidelines. Data quality was assessed for each parameter and uncertainty analysis applied to identify priorities for future improvement. The resulting inventory report was reviewed by a UNFCCC-certified expert reviewer from New Zealand and by the inventory core team. The final inventory, covering emissions from all relevant sources of methane and nitrous oxide from 1995 to 2017, was incorporated in Kenya's third national inventory report (State department for livestock 2020).

Continuous improvement

The Tier 2 inventory clearly showed that at national level, the GHG emission intensity of dairy production has been decreasing over time (Figure 5). This evidence, together with continued interest of investors in the dairy sector, informed updating of Kenya's NDC, which prioritizes "efficient livestock management systems" as a mitigation strategy.

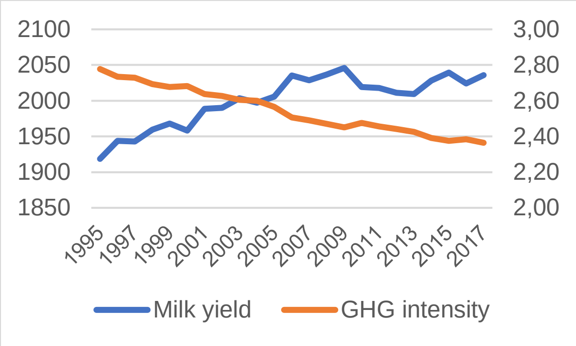

Figure 5. GHG emission intensity (kg CO_2-e kg milk^{-1}, right axis) and annual milk yield cow^{-1} (litres, left axis) in Kenya.

In 2021, the State Department for Livestock added new staff to its Climate Change Unit (CCU), and the Global Research Alliance on Agricultural Greenhouse Gases supported hands-on training on how to update the inventory using the most recent cattle population data. The State Department for Livestock is now planning to further strengthen inventory management by the CCU and is exploring options for long-term improvements in the data collection systems used by county governments for dairy cattle herd structure, milk yields, diet composition and manure management. It is also planning to extend the Tier 2 method to other ruminant species.

Kenya is also in the process of developing a registry of climate change adaptation and mitigation activities. Developing cost-effective methods to estimate the GHG effects of the many dairy development initiatives in the country will also be necessary to enable the country to report progress in implementing its NDC.

Key messages

- Stakeholders perceive benefits of a Tier 2 inventory when there is a clear policy need to track changes in emissions in the sector.
- A clear mandate and leadership from the ministry in charge of livestock was essential to convening stakeholders to support the inventory development process.
- Even if there are data gaps, a Tier 2 inventory can be compiled using the best available data.
- Improvements in local government data collection systems will make key contributions to continuous improvement of the inventory.
- Kenya is now planning to apply the experience gained in Tier 2 methods to GHG inventories for other ruminant species.

4 Towards sustainable livestock systems

In the introduction of this research paper we presented a series of principles for sustainable livestock development. The idea of the principles as developed by the World Bank (2019) was that each of the principles alone will lead to sustainable development. This makes them applicable in many contexts, in many farming system typologies, and in many political realities. The case studies presented are from four continents and show a diversity of contexts and farming systems. The interventions described in the case studies were not formulated on basis of the principles. In this chapter we will reflect on how, retrospectively, the principles are apparent in the case studies. By doing so, we illustrate that the principles are an entry point to sustainable development and we conclude that the 7th principle (create an enabling environment) is the most important principle, because in this principle the top-down objectives from policy and the bottom-up objectives of those that have to support their livelihoods from future ASF-production meet.

The first principle (*Principle 1. Contribute to a sustainable food future.* A systemic principle which implies considering of non-livestock options to meet the targets of a food system) is apparent in the introduction of circularity in food production including dairy farming in the Netherlands. Milk supply to an international market is no longer the principle aim but replaced by a role for to convert wastes and use lands unsuited for crop production to contribute to the national diet. A reduced inclusion of ASF in the national diet can be a consequence of this strategy.

In most of the other interventions presented in the case studies, the position of livestock in national food production and economy is implicitly maintained or even expanded, though with increased sustainability of production. *Principle 2. Enhance carbon stocks* is positively addressed in the improved farming practices on grasslands in New Zealand and Colombia.

Higher productivity goes along with reduced herd sizes with still high national outputs (which is the essence of *Principle 3. Improve efficiency at animal and herd level)*. Lands can be spared for restoration of native forests and grassland (New Zealand) or partly reforested (Colombia) which results in additional carbon sequestration. The tier-2 inventory system in Kenya addresses productivity differences and GHG emissions and can become a tool for policy making for livestock development. The Dutch dairy sector has a high productivity. Herd sizes have been curtailed by past policies and manure regulations, but at present a further reduction of the herd size seems inevitable to meet targets for climate change mitigation and biodiversity. Alternative farm strategies to get income and introduction of a circular food systems are facilitated by policies to achieve reduced herd sizes in the Netherlands. In the present dairy production in the Netherlands, feed imports are important, and this may also be the case in land-limited peri-urban systems in Kenya (Oosting et al. 2014).

Principle 4. Source feed sustainably and *Principle 5. Couple livestock to land* apply to the intensive production systems of the Netherlands and Kenya, because such systems import feeds and have high animal densities; Principle 4 since the sustainability of production of feeds at its origin determines the sustainability of livestock production at the destination. Sustainability challenges at the origin of feed production comprise land use change i.e. deforestation, excess or under-fertilization, use of pesticides and societal issues. Principle 5 applies because losses of N and P to the environment are highly associated with import of feeds and with limited land availability for manure application. Extensification of livestock farming reduces the need for feed imports and will concomitantly reduce the risk for use of less sustainable feeds and the manure production/land ratio.

Principle 6. Minimize fossil fuel use is not explicitly addressed in any of the case studies. Nevertheless, this principle is in each countries' national policy. Livestock farms can contribute to production of renewable energy e.g. by biogas production, and allocating space for solar panels and wind mills.

Principle 7. Foster an enabling environment has been or will be essential in all interventions described in the case studies. Many policies and interventions are top-down, but farmers and processors and other chain actors need to adopt and implement the interventions. Regulation is important, but also facilitation, allowing room for flexibility, and involvement of farmers and chain actors into the processes. Processes of adoption and implementation should be long term and farmer- and chain actor-inclusive as explicitly described in the New Zealand case study. If the dichotomy between those actors who will produce and process the food and those who want to achieve climate change mitigation and biodiversity objectives, is not bridged, it will be very difficult to meet the triple objective of ASF production i.e. of food security, climate change mitigation and biodiversity concomitantly. The case studies presented in this research paper, however, show that small and large wins have been achieved and this gives hope for the future!

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