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Livestock systems: their role in the transformation of food systems in the context of climate change

Discussion paper by the Swiss National FAO Committee (CNS-FAO)

Pictures: N. Bourgeois, World Expo 2015, Milan, Italy

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Livestock systems: their role in the transformation of food systems in the context of climate change

This working paper by the Swiss National Committee to the Food and Agriculture Organization of the United Nations (CNS-FAO) serves to orient the Swiss Government and interested stakeholders on the transformation of the livestock sector to support livelihoods, human health and nutrition, and the ecosystem in a more inclusive, resilient and sustainable way. As a crucial component of food systems, the wider society and ecosystems, the livestock sector must be an integral part of the transformation path along with other systems components such as agriculture, processing, and food logistics.

The discussion paper was elaborated by the Swiss National Committee to the Food and Agriculture Organization of the United Nation (CNS-FAO), a multi-stakeholder consultative body nominated by the Swiss Federal Council.

A working group on "Livestock and Climate" was created within the CNS-FAO specifically for the preparation of this document. The members of the working group participated in the drafting of the document and provided regular feedback.

Among others, the following CNS-FAO members (in alphabetical order) took part in this working group: Bourgeois Lüthi Nancy (Lecturer and researcher in International Livestock Systems, HAFL), Erhard Robert (Head of Dairy, Corporate Sustainable Agriculture Development, Nestlé), Lüthi Rudolf (Head of the Water, Food and Climate Department, Helvetas Swiss Intercooperation), Niggli Urs (President of the institute for Agroecology), Sonnevelt Martijn (Executive Director ETH World Food System Center).

CNS-FAO as an entity as well as individual members provided detailed feedback that was incorporated into this final version. All contributions are gratefully acknowledged.

Abbreviations

AMIS	Agricultural Market Information System
AMR	Antimicrobial resistance
ASF	African Swine Fever
ATF	Animal Task Force
BC	Before Christ
BP	Before present
BPA	Biodiversity Promotion Area
C	Carbon
CAP	Common Agricultural Policy
CCAC	Climate Clean Air Coalition
EU	European Union
CNS-FAO	Swiss National Committee to the Food and Agriculture Organization of the United Nations
COP	Conference of Parties
FAO	Organisation of the United Nations for Food and Agriculture
FOAG	Federal Office of Agriculture
FOEN	Federal Office for the Environment
GASL	Global Agenda for Sustainable Livestock
GFFA	Global Forum for Food and Agriculture
GHG	Greenhouse gas
Gt	Gigaton
GTP	Global Temperature Potential
GWP	Global Warming Potential
HPAI	Highly Pathogenic Avian Influenza
ICLF	Integrated crop-livestock-forestry
K	Potassium
KJWA	Koronivia Joint Work on Agriculture
LCA	Life cycle assessment
LDCs	Least-developed countries
LDF	Livestock-derived food
LMIC	Low- and middle-income countries
LU	Livestock Unit
MT	Megaton
N	Nitrogen
NCD	Non-communicable diseases
NTFP	Non timber forest products
NUE	Nutrient use efficiency
OIE	Office International des Epizooties
P	Phosphorus
PN	Pâquier-normal
SDC	Swiss Agency for Development and Cooperation
SCNAT	Swiss Academy of Sciences
SECO	State Secretariat for Economic Affairs
SOC	Soil Organic Carbon
TCA	True cost accounting
UAA	Utilised agricultural area
UNEP	United Nations Environment Programme
UNFSS	United Nations Food Systems Summit
WELI	Women's Empowerment in Livestock Index

WOAH	World Organisation for Animal Health
WWF	World Wildlife Fund

Glossary

Agricultural land	The total of arable land, permanent crops and permanent meadows and pastures.
Arable land	Land on which the vegetation is dominated by production of field crops (e.g., maize, wheat, and soybean). The land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category.
Blue water	Freshwater flows originating from run-off or percolation, contributing to freshwater lakes, dams, rivers, and aquifers. Soil moisture is considered blue water if it originates from blue water added through irrigation, is the result of hydrological events (e.g., flooding), or comes from springs or capillary rise.
By-product	Material produced during the processing of livestock or a crop product that is not the primary objective of the production activity.
Co-product	Product from a plant cultivation system that can be used either directly as feed or as raw material in food or feed processing. In contrast to by-products, co-products are any of two or more products coming from the same unit process or product system that are of primary objective and with higher financial value.
Cropland	Land used for the cultivation of crops, both temporary (annuals) and permanent (perennials), and may include areas periodically left fallow or used as temporary pasture. The total of areas under "Arable land" and "Permanent crops".
Feed	Any single or multiple materials, whether processed, semi-processed or raw, which are intended to be fed directly to food-producing animals.
Fodder	Forage harvested from both cultivated and non-cultivated land, fed intact to livestock, including fresh and dried forage.
Grasslands	Large open area of country covered with grass, particularly when used for grazing.
Grazing	Animals feeding directly on growing grass, pasture, or forage crops.
Green water	Precipitation that is stored as soil moisture and eventually transpired or evaporated.
Permanent meadows and pastures	Arable land used for livestock grazing. They include both managed and natural pastures, as well as a range of land cover types used for rangelands, such as grassy and woody savannahs.
Silage	Forage harvested and preserved (at high moisture content generally > 500 g/kg) by organic acids produced during partial anaerobic fermentation.

Sources: definitions by FAO, 2019, and FAO term portal.

Table of contents

1. Introduction: a holistic approach to food systems

Systems consist of a group of components, interacting to various degrees with each other. They are characterised by the notion of unity, defined by a boundary. Livestock are components of livestock systems, interact with grassland management and arable cropland, change the landscape and either maintain or, in the worst case, exhaust the natural resources of soil, water, air, and biodiversity. Livestock is an integral part of the entire food system. Thoroughly understanding livestock systems is crucial and, to this purpose, they have been classified by different authors[1], using different methodologies and criteria.

The most widely used classification is the one defined by Seré and Steinfeld (1996) according to five main criteria: 1) degree of integration of livestock into the cropping system, 2) the relation to land, 3) the intensity of production, 4) the relation to water resources, and 5) the agroecological zone.

The classification results in two main categories: solely livestock and mixed-livestock cropping, and four subcategories: landless and grassland-based solely livestock systems, rainfed mixed and irrigated mixed systems. When agroecological zones[2] are considered, the classification counts 11 systems (Annex 1).

In all 11 systems, livestock entail multiple roles and fulfil many functions, which vary in importance. Livestock's roles can range from production of high value <u>products</u> (eggs, meat, milk, fibres, hides), to <u>services</u> such as cash generation and food security, asset building, collaterals, insurance, risk spreading, manure/nutrient flows, energy, draught power, pack, cultural, ecosystems services, religious and spiritual value, mental and physical health services, among others (Alders et al., 2021).

Livestock is not reduced to a single role or function in any of the 11 systems. This means that any intervention targeting one specific function of livestock in each system will inevitably impact another function: neutrally, positively, or negatively.

When functions override others in a given system, the equilibrium of the whole is threatened, and negative impacts arise. Overpopulation of livestock in some areas, structural shifts between production of species (e.g., less ruminants, more monogastric), changes in feeding patterns (e.g., soybean to ruminants), and **overconsumption** of animal products will entail environmental costs such as biodiversity loss, soil, air and water pollution, land degradation and erosion, greenhouse gas (GHG) emissions, animal diseases (enzootic or pandemic), and human health issues (zoonotic, food-borne, or other), among others.

Interestingly, the **underpopulation** of livestock in specific areas also results in environmental costs: biodiversity loss, e.g., in boreal zones (Herzon et al., 2022), in Alpine territories (Moustier, 2006; Koch et al., 2013), soil nutrient mining by crops, crop failure, soil, water and air pollution due to synthetic fertiliser used as manure replacement, absence of ecosystem services (control of invasive species, seed dispersion, soil fauna), and human malnutrition, among others.

[1] Wittlesey 1936; Grigg, 1972; Ruthenberg, 1980; Seré and Steinfeld, 1996; Dixon et al., 2001.
[2] 1) Hyper arid/arid, 2) temperate, 3) subhumid/humid.

2. Recent developments

Food systems evolve and adapt to changing policy, and economic, societal, technological, legal, and environmental factors. Current food systems were largely shaped in the aftermath of World War II and the food shortage or even famines which followed. As economies recovered and people became more affluent, the consumption of staple food diminished and the consumption of livestock-derived food (LDF) increased (Vranken et al., 2014). This phenomenon was accompanied by the Green Revolution which profoundly changed agriculture and cropping activities and ultimately the roles and functions of livestock in these systems (Mazoyer and Roudart, 2002).

Since then, imbalances in the food system were created by an increasing demand for food, in general, and specifically for high-value products such as LDF, vegetables, fruits, nuts, and luxury foods such as coffee, tea, and cocoa. The high demand for such products is triggered by population increase and changes in diet patterns resulting from urbanisation, affluence, and globalisation (so called "*westernisation of the diet*"). These mechanisms were described extensively in the publication *Livestock to 2020: the next food revolution* by Delgado et al. (1999). It must be noted that the same mechanisms induce other consumption behaviours not related to food, such as mobility, communication, leisure, convenience, clothing, and consumption of non-food common or luxury goods, among others.

Since the publication of *Livestock's Long Shadow* by Steinfeld et al. in 2006, the livestock sector has been thrust into the spotlight for its direct and indirect contribution to GHG emissions and, therefore, climate change and other negative impacts. More recently, the publication of *The Planetary Health Diet* by the EAT-Lancet Commission on Food, Planet, Health (Willett et al., 2019), and the Food Systems Summit organised by the United Nations (UNFSS) in 2021, added additional pressure on the livestock sector by strongly advocating for a transformation of the global food system, through a drastic reduction in consumption of LDF, especially meat. Unfortunately, recommendations from the EAT-Lancet report and several coalitions which emerged from the UNFSS largely ignore the systemic nature of the food system and its components (livestock, crops, ecosystems). By doing so, recommendations often fail to address important trade-offs that arise by "*moving the cursor*" from one spectrum extreme to the other.

In Fiji in 2017, the 23rd Conference of the Parties (COP23) launched the Koronivia Joint Work on Agriculture (KJWA). This formal decision (decision 4.CP/23) highlights the role of agriculture not only as a contributor and victim of climate change, but also as a solution to tackle climate change; therefore, livestock became an important part of the Koronivia process and roadmap.

Our position paper aims to present and discuss the role of livestock for the transformation of the food system in the context of climate change, including the trade-offs at all levels arising from the multifunctionality and inherent complexity of livestock's roles. As members of the Swiss National FAO Committee (CNS-FAO), we look primarily at global issues pertaining to livestock and relate them to Europe and Switzerland whenever relevant. We present and discuss the roles and functions of livestock in global food systems first, and refer to specific challenges in Europe and Switzerland. We always consider the intrinsically complex nature mentioned in the introduction.

This position paper is based on extensive literature research done by the authors with search engines (Google Scholar) and databases (CAB Abstract).

Recommendations at the end of this paper are based on inputs from a wider written consultation process and a participatory workshop with CNS-FAO members and members of the following federal offices: Federal Office of Agriculture (FOAG), State Secretariat for Economic Affairs (SECO), Federal Office for the Environment (FOEN), and Swiss Agency for Development and Cooperation (SDC). A written consultation was also conducted with leading scientists from the Forum for Climate and Global Change (ProClim) at the Swiss Academy of Sciences (SCNAT).

The document is structured using the four sustainability domains which emerged from the 10th Global Forum for Food and Agriculture (GFFA) in Berlin in 2018 (FAO, 2018a):

1) food and nutrition security,
2) livelihood and economic growth,
3) animal health and animal welfare,
4) climate and natural resource.

These four sustainability domains also frame the Global Agenda for Sustainable Livestock (GASL).

3. Contribution of livestock, agriculture, and the entire food system to GHG emissions, climate change and environmental issues

Summary of this chapter:
The Global Warming Potential (GWP), a central metric to measure emmissions, has some limitations as it compares a short-lived gas such as methane with long-lived gases such as CO_2 and N_2O. As methane is estimated to have 10 times higher GWP than CO_2, but a much shorter life in the atmosphere, public attention on methane is intense, and policy measures focus on methane to rapidly reduce GHG effects (FAO, 2023).

In 2020, total anthropogenic GHG emissions were estimated to have reached 52 Gigatons (Gt) CO_2eq. Expressed in CO_2eq and GWP, the global food system accounted for 31% of total anthropogenic GHG emissions in 2020, compared to 38% in 2000. This decreasing share is a concenquence of the faster growth in emissions from other sectors. In the agricultural sector, ruminants are the largest contributors of methane and, hence, warming potential.

Direct and indirect GHG emissions from the livestock sector are estimated to reach 7.6 Gt CO_2eq – 47% of food systems emissions and 14.5% of the global anthropogenic GHG emissions. Cattle production is responsible for 61% of all emissions from the livestock sector. FAO estimates that GHG emissions from the livestock sector can be reduced by 33%, via two ways: reducing livestock numbers and increasing efficiency of production through more productive animals.

Livestock production depends on natural resources such as land and water. At global level, most agricultural land used to produce animal products is grassland. Arable land currently used to exclusively produce animal feed (such as grains) represents a small fraction of the total agricultural land. As far as crop rotation allows, such arable land should be devoted to produce food, instead of feed, in the future. A non-negligible proportion of grassland could potentially be converted to arable land to produce food for humans instead of grass for cattle. However, the consequences of ploughing such fields for cropping are estimated to be worse for the environment than the current practices.

Opening grassland fields would result in losses of organic material, CO_2 release, ecosystem services, and biodiversity, and impact water retention. In the case of water, when "blue water use" (irrigation) is considered, the water footprint of livestock products (per kg, calorie and protein) is often lower than the footprint of vegetal products.

The transition towards low-carbon food systems needs to take into account important trade-offs, such as GHG reduction vs water efficiency and feed/food competition vs ecosystems services, and search for solutions which take local agroclimatic conditions and other characteristics into account.

The Kyoto Protocol, signed in 1997 and operational in 2005, regulates six gases which impact climate change: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6). A seventh gas, nitrogen trifluoride (NF_3), was added in 2022.[3] To allow for comparison, the warming potential of all gases was measured against the warming potential of CO_2, taken as a reference. GHG emissions are therefore expressed as CO_2 equivalent (CO_2eq). The impact of these gases on climate is expressed in two ways: GWP and the global temperature potential (GTP). The main difference between these two metrics resides in the time factor: GWP being a function of a time span and GTP of a point in time. The global warming potential over 100 years (GWP_{100}) of gases expressed as CO_2eq has been the main metric used to quantify emissions so far. This approach however entails a flaw, as it compares a short-lived gas, such as methane, with long-lived gases, such as CO_2 and N_2O. When comparing gases, the time span should be taken into consideration.

In short:

- Increasing CO_2, N_2O and CH_4 emissions will increase GWP, but at different rates: fast for methane, slow but constant for CO_2 and N_2O.
- Decreasing CO_2, N_2O and CH_4 emissions will decrease GWP, but at different rates: fast for methane, slow but constant for CO_2 and N_2O.
- Constant emission levels of CH4 do not contribute to temperature increases, while constant CO_2 and N_2O emissions do further increase temperatures as they remain in the atmosphere for longer.

These findings call for a rapid reduction of methane emissions. This will have an impact in the short term and, therefore, "compensate" for increasing, constant or even decreasing CO_2 and N_2O emissions which have a delayed impact due to their longer persistence in the atmosphere.

The main greenhouse gases (GHG) emitted by agriculture are CO_2, CH_4 and N_2O. In agriculture, fluorinated gases (F-gases) are mostly emitted in cold chain processes.

3.1 Components of food systems emissions

In 2020, total anthropogenic GHG emissions were estimated to have reached 52 Gigatons (Gt) CO_2eq, compared to 54 Gt CO_2eq in 2019. The 4% reduction was imputed to the impacts of the COVID-19 pandemic (FAO, 2022a).

Expressed in CO_2eq and GWP, the global food system accounted for 31% of total anthropogenic GHG emissions in 2020, compared to 38% in 2000.

[3] Added in 2022 during the Doha round.

This decrease was imputed to the faster growth in emissions from other sectors. Indeed, global GHG emissions keep increasing and emissions from the global food system increased by 9% between 2000 and 2020[4] to reach 16 Gt CO_2eq.

Asia (6.6 Gt CO_2eq) and the Americas (4.3 Gt CO_2eq) account for the largest share of global food systems GHG emissions because they host the largest proportion of the world population, among other reasons. When looking at emissions regionally, it appears that the share of GHG emissions induced by the food system compared to total anthropogenic GHG emissions varies greatly across regions.

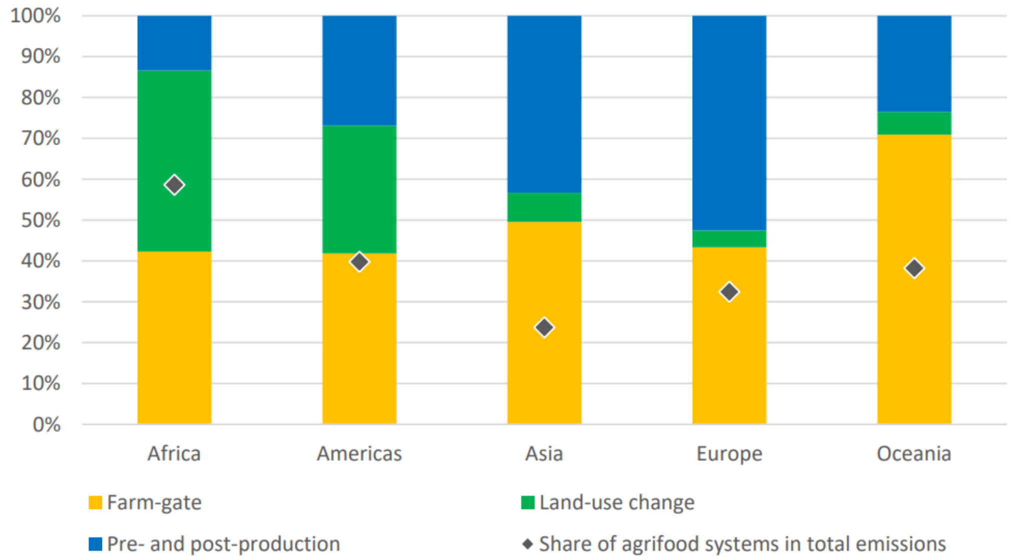

Figure 1. Regional agrifood systems emissions and share in total emissions (2020) (FAO, 2022a).

Africa exhibits the highest share of its total anthropogenic GHG emissions from its food system (59%), followed by the Americas (40%), Oceania (38%), Europe (32%), and Asia (24%). These proportions reflect the importance of each region's population and the relative importance of agriculture. Total GHG emissions vary greatly not only across regions, but also according to the components of the food systems. Globally, food systems GHG emissions are shared across three main areas, as illustrated in Figure 2 (FAO, 2022a). Production on farms generates the highest share of GHGs in the food system, followed by processes along the value chain. Land-use change represents one fifth of all food systems emissions.

[4] Against 50% for emissions from the non-food sector.

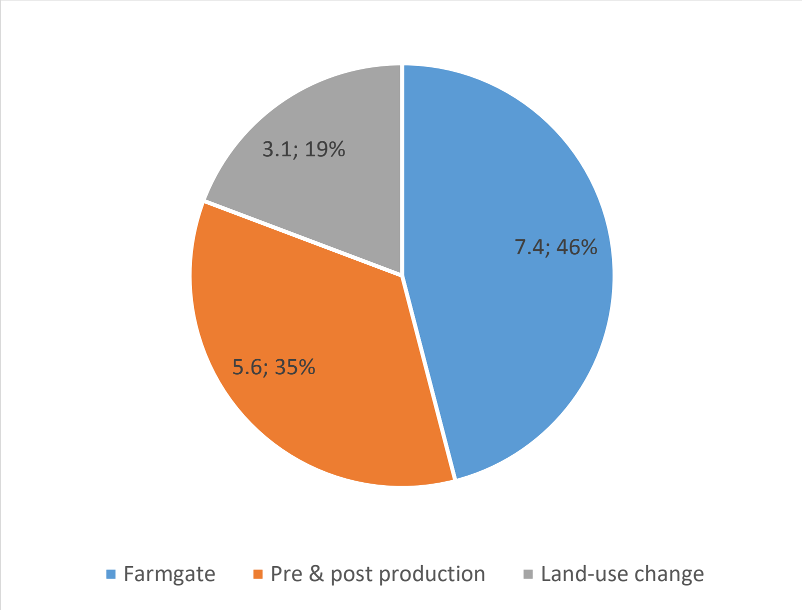

Figure 2. Total (CO_2eq in Gt) and relative (in %) GHG emissions across the different components of the global food system in 2020 (FAO, 2022a).

The share of GHG emissions within food systems related to production are highest in Oceania (71%), Asia (50%) and the Americas (43%), while the share of emissions related to pre- and post-production are highest in Europe (53%). The proportion related to land-use change is highest in Africa (44%) and the Americas (31%), reflecting deforestation issues (FAO, 2022a).

Changes in GHG emissions from food systems over the past 20 years vary greatly across regions as well: while emissions decreased in Oceania (-33%), the Americas (-9%) and Europe (-1%), they increased in Africa (+35%) and Asia (+20%).

Emissions from the three components of the food system, however, grew at a different pace over the past 20 years: emissions growth is highest at pre- and post-production (+45%), followed by production (+13%). Emissions from land-use change decreased by 29%, which indicates a decrease in the deforestation rate over the past 20 years.

Within the food system, deforestation and enteric fermentation from ruminants are the two highest single emitters of GHGs: 2.9 Gt CO_2eq (18.2%) from deforestation and 2.8 Gt CO_2eq (17.5%) from methane (FAO, 2022a). Together they contribute 36% of the total GHG food systems emissions (in CO_2eq).

The case of methane

Methane (CH_4) is currently estimated to be the second most potent greenhouse gas after carbon dioxide (CO_2). Methane is estimated to have 10 times higher warming potential than CO_2, but a much shorter life in the atmosphere (10 years versus up to 200 for CO_2). These characteristics explain the strong policy and public focus on methane to rapidly reduce greenhouse effects.

Methane is produced by methanogenic microorganisms thriving in anoxic or hypoxic milieus and is emitted through natural phenomenon or through anthropogenic activities. Sources of methane emissions are differentiated according to their origin.

- **Natural** methane sources are water (freshwater, wetlands, oceans), geological conditions, termites, wild animals, and permafrost soils. They represent 40–50% of total CH_4 emissions (depending on how calculations are made).
- **Anthropogenic** methane sources, which represent 50–60% of total CH_4 emissions, are fossil fuel (oil, coal, gas) extraction/processing and use, waste management (solid waste and waste water), and agriculture (rice fields and ruminant production). It has been estimated that emissions from fossil fuel methane were largely underestimated in the past three decades (Schwietzke et al., 2016).

Figure 3 shows estimated methane emissions from natural sources (green columns) and anthropogenic sources (blue columns).

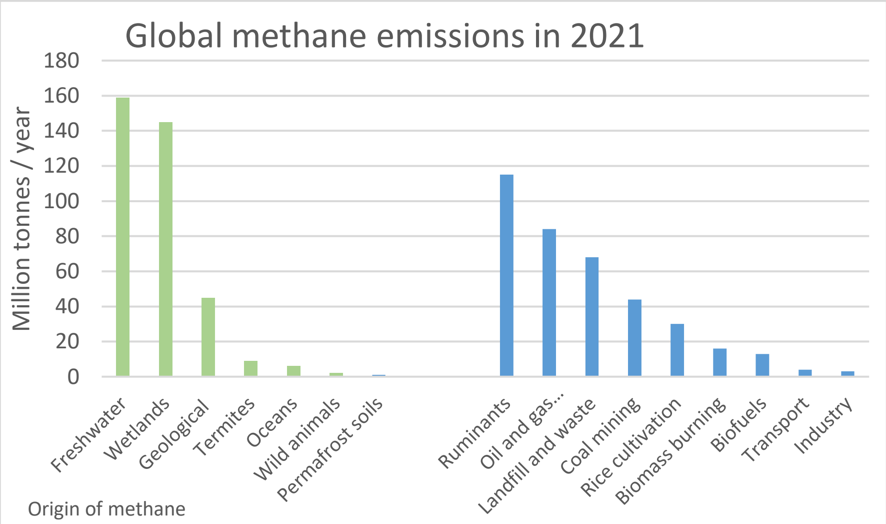

Figure 3. Global methane emissions (UNEP and CCAC, 2021).

In the agricultural sector, ruminants are the largest contributors of methane. Ruminants are hooved, herbivorous mammals belonging to the *Ruminantia* suborder, such as domestic animals including cattle, sheep and goats, but also wild animals such as deer, antelopes, gazelles, moose, and giraffes. Ruminants feed on plant material such as grasses, legumes, shrubs, trees, and leaves. While each ruminant species has its own grazing or browsing behaviour, all have a common characteristic: they possess four digestive vats and they ruminate. The first vat is the rumen, a large fermentation chamber where grazed or browsed fodder and feed is broken down by the specific rumen fauna. The latter consists of protozoa, bacteria and fungi which break down the fibrous plant material (cellulose, hemicellulose, lignin) into smaller pieces able to enter the second fermentation vat, the reticulum.

Plant material which is not sufficiently pre-digested in the rumen is regurgitated to be chewed and swallowed again. The process continues until plant material is sufficiently small enough to enter the reticulum. Digestion in the rumen is done in anaerobic conditions by methanogenic microorganisms. Most of the methane, a side product of digestion, is emitted through eructation during the rumination process (when ruminants chew the cud).

Camelids are pseudo ruminants, as their stomachs consist of three chambers. They do produce methane but to a lesser extent than ruminants. Monogastric herbivores such as horses also produce methane during hindgut fermentation, but to a lesser extent than ruminants or camelids.

While methane emissions from livestock consists mainly of eructed gas, they also entail gas emitted from manure. This is especially the case of methane emitted from monogastric production (poultry and pigs).

Methanogenic bacteria, though characteristic of the rumination process, are not specific to ruminants. In addition to pseudo-ruminants or the herbivores mentioned above, they are also found in termites, which digest lignin, and in the digestive tract of humans.

3.2 Contribution of livestock to anthropogenic GHG emissions

The direct and indirect GHG emissions from the livestock sector are estimated to reach 7.6 Gt CO_2eq (GLEAM, 2022), which corresponds to 47% of food systems emissions and 14.5% of global anthropogenic GHG emissions. Cattle production is responsible for 61% of all emissions from the livestock sector, reflecting both cattle numbers and the fact that they emit methane. Buffaloes and small ruminants, although they also emit methane, are the smallest contributors to total GHG livestock emissions due to their smaller population, expressed in livestock units. Cattle and small ruminants offer the best perspectives for emission reductions in proportion to their total emissions.

FAO estimates that GHG livestock-sector emissions can be reduced by 33% by two ways: **reducing livestock numbers** and **increasing efficiency of production** through more productive animals. In comparison, rice production, as a large methane emitter, contributes 1.5% to total anthropogenic GHG emissions.

Over the past 20 years, emissions intensities expressed as CO_2eq/kg of product decreased for a range of LDF (meat and milk from various species, eggs from hens), as well as crops. The highest reduction of GHG emissions was achieved in raw cow milk (-24%), followed by rice (-14%), other cereals (-11%) and eggs (-11%). Although emissions intensities decreased by 8% for beef, they remain by far the highest, due to enteric fermentation.

Emission intensities for a specific product vary greatly across systems and countries. In the milk sector, for instance, emissions intensities for milk among the top-10 milk producers vary between 0.5–1.4 CO_2eq/kg milk. Emission intensities are highest in Pakistan and India; figures partly reflecting the fact that, in these countries, ruminants are fed mainly with coarse feed inedible to humans (e.g. crop residues, co-products or by-products). Therefore, they directly and indirectly contribute to food security, without competing with food.

These figures indicate that future efforts to curb global anthropogenic emissions should focus on:

- Reducing emissions from the non-food sector (the fastest growth rate of emissions).
- Within the food sector, further reducing: CO_2 emissions from land-use change (deforestation), methane emissions from livestock enteric fermentation, manure, rice fields, and landfills, as well as CO_2 emissions from households.

However, reducing GHG emissions from the food system through livestock reduction should not be done at the expense of other important direct (LDF, cash) and indirect (manure, draught power) livestock contributions to food and nutrition security and poverty alleviation, especially in countries where hunger and malnutrition prevail.

The contribution of livestock to climate change has been amply documented and discussed. At the same time, livestock farming, like other parts of the food sector, is a victim of climate change.

In their concept of "*safe climatic space*", Kummu et al. (2021) estimate that 5% (against 8% for crops) of the world's livestock production will fall outside the so-called safe climatic space under the conservative scenario of 1.5–2°C temperature increase. Under the more likely scenario of > 2°C increase, 34% of the world's livestock production would fall outside the safe space by 2090 (against 31% for crops). The most affected regions are South and Southeast Asia, as well as sub-Saharan Africa; in other words, large tracts of areas currently used by livestock will become unsuitable for livestock production.

3.3 Ammonia

Ammonia (NH_3), a gaseous form of nitrogen (N), is not a GHG, but an air pollutant. The gas is released from urea contained in urine. As it is volatile, ammonia is easily transported by wind and negatively impacts the environment through acidification and eutrophication of natural milieux such as forests, extensive grasslands, and bogs, thereby threatening biodiversity. Ammonia volatilisation threatens both ecosystems and human health, and represents a nitrogen loss for cropping activities.

Switzerland has an international commitment to reduce ammonia emissions, the bulk of which originates from cattle production. Emissions occur when animals are kept indoors or graze outside, as well as when manure or slurry is stored or applied. The highest losses occur during slurry application and housing of animals.

Ammonia emissions decreased dramatically by 23% between 1990 and 2004, partly due to reductions in livestock numbers, but mainly due to farm nutrient-management policies that led to reduced nitrogen fertiliser use. Since 2004, emissions have stagnated, mainly due to new animal welfare policies requiring animals to spend more time outdoors. Gains obtained by better slurry-spreading technologies were offset by increased grazing of cattle on pastures (Kupper et al., 2022). This example shows the complexity of tackling a problem when different policies, emanating from the same office, defeat the expected outcome.

3.4 Water footprint

The impact on the water footprint of the diet of reducing consumption of animal products in favour of plant-based products needs to be examined in depth. Production of LDF is often criticised for being inefficient in terms of water use. Mekonnen and Hoekstra (2012) deduced that 15,415 litres of water is necessary to produce one kilogramme of beef, which makes it by far the least-efficient water user when compared to nuts, vegetables, fruit or grains. The scope of this number is however often omitted in conversations and publications for the wider audience.

The water footprint is disaggregated into three components: "green water" (rainwater), "blue water" (water used for irrigation) and "grey water" (a theoretical category indicating how much clean water is used to dilute polluted water to render it usable again). In view of water resources becoming scarcer, the crucial water footprint component is blue water, and only this should be used for comparisons (WWF, 2021b). In the case of beef, 93.5% of the water used to produce beef is green water. Its blue water footprint is 550 L/kg, which is half of the blue water footprint of nuts (1367 L/kg), for example; actually, when blue water efficiency is expressed per kg in calories, protein and fat, all LDFs perform better than nuts. Most LDFs also perform better than fruits, vegetables, and cereals when the blue water footprint is expressed per kg of protein or fat.

Such elements need to be considered in the wider discourse on sustainable diets. The World Wildlife Fund (WWF) assessed GHG emissions (WWF, 2021a) and the water footprint (WWF, 2021b) of the current "standard" diet in Germany, as well as of three "scenarios" with flexitarian, vegetarian, and vegan diets. The current diet, consisting of a high proportion of LDF, performed worst in terms of GHG emissions, while the vegan diet was best.

Nevertheless, when the water footprint of the four diets was scrutinised, the current diet, rich in LDF, performed best, while the vegan diet was worst. The study showed that a shift from diets rich in LDF to more plant-based diets should carefully consider the type and origin of products. Citrus, avocadoes, and nuts originating from countries where rainwater is scarce should be avoided and replaced by local products produced in rainfed conditions.

3.5 Land use by livestock

According to the latest statistics, Earth's total land area (excluding Antarctica) is 13.1 billion ha and is almost equally shared across three categories (Fig. 4).

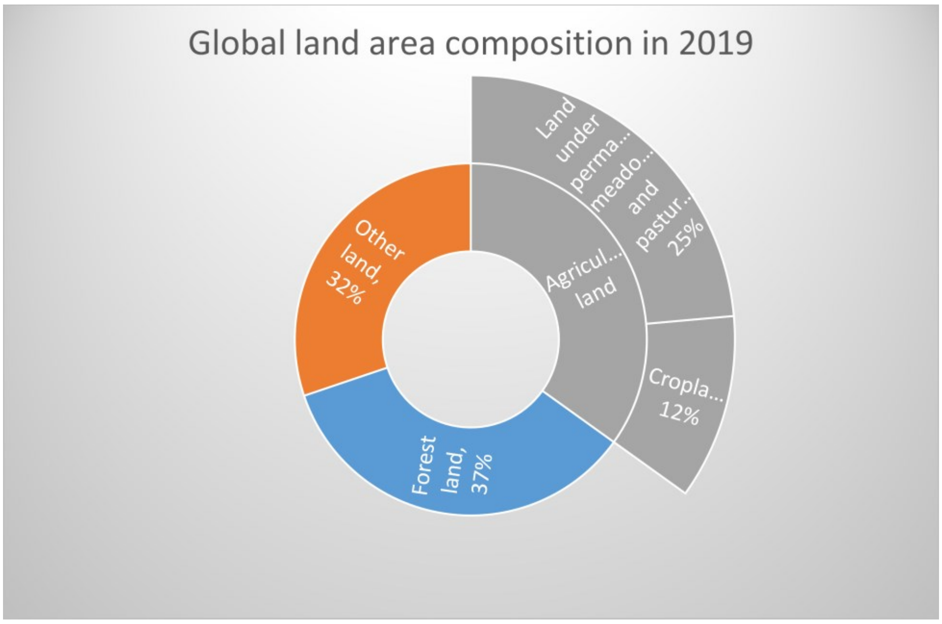

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Figure 4. Global land area composition in 2019 (FAO, 2021).

Forest land covers 4.1 billion ha, agricultural land 4.8 billion ha, and other land (urban land, infrastructures, desert) 4.2 billion ha. Livestock is reported to use an important share of Earth's land area. In reality, livestock uses specific areas of the total land surface: agricultural land comprised of croplands (1.6 billion ha) and grasslands (3.2 billion ha). These grassland areas are further split into marginal grasslands (1.4 billion ha) not used by livestock and permanent meadows (2 billion ha) used by livestock.

According to Mottet et al. (2017), 2.5 billion ha (which corresponds to 52% of the agricultural land) are currently used to feed livestock (Fig. 5).

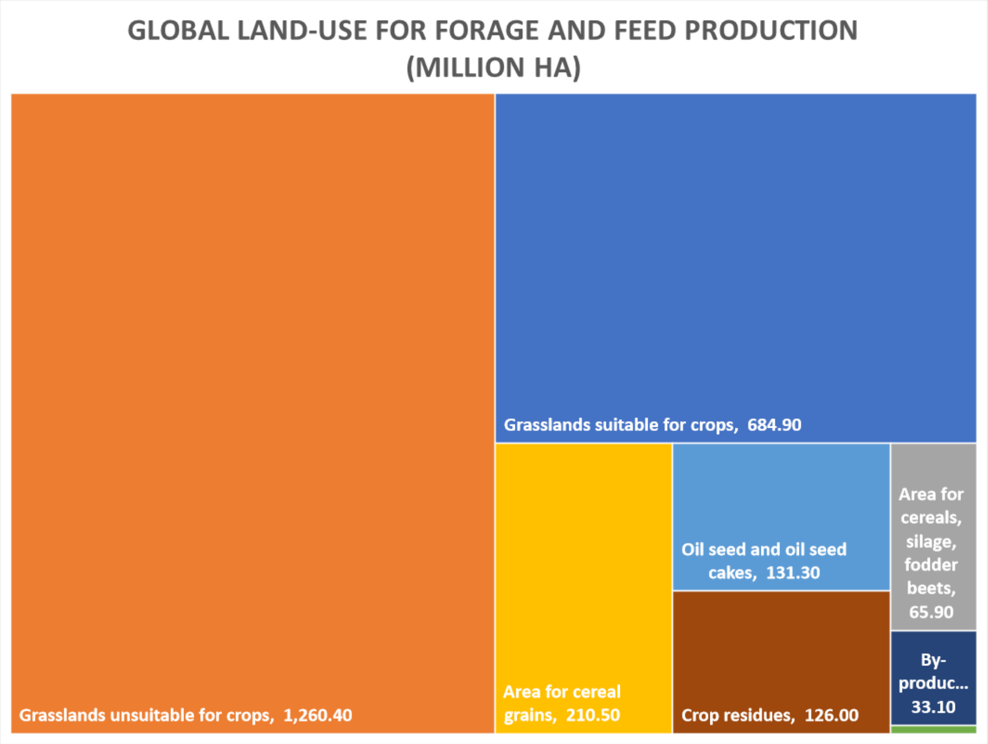

Figure 5. Land area for fodder and forage in 2017 (Mottet et al., 2017).

Land-use change and the case of deforestation

Livestock production is often cited as an important source of deforestation, if not the main cause, especially in countries in Latin America (WWF, not dated). Indeed, in countries such as Brazil, Bolivia, Peru, and Colombia, large tracts of pastures to sustain beef or dairy production are cultivated on lands gained from forests. This is the case in the Amazon, as well as in the Cerrado, a major biome spanning across Brazil, Bolivia and Paraguay. The Brazilian Cerrado is estimated to have lost 80% of its forest, sometimes called the "inverted forest" because of its massive carbon storage in its extensive root system. There, soybean production occupied 17.66 million ha and sugarcane 3.08 million ha in 2020 (MapBiomas Brasil, 2020).

Deforestation is, however, more complex than "just" felling or burning trees to replace them by grass and cattle. Deforestation usually starts with the construction of roads to access forest tracts to fell and sell the most precious trees, a business and a main incentive to harvest forest per se.

Mining is often also cited as a main driver behind deforestation (FAO, 2007). The main goal to clear forest is however to gain agricultural land (Mauricio, personal communication 2023). This phenomenon is known in Brazil as the "*expansion of the frontier*" (Drummond and Barros-Platiau, 2005).

Once the forest is cleared and natural grasses grow, cattle ranchers, and not crop farmers as stated by FAO (2007), occupy the cleared plot. Crop production cannot de done immediately after felling trees, as too much mechanisation is needed to remove leftover woody materials such as roots and branches (Mauricio, personal communication 2023). Such pastures are grazed extensively with a low-stock density of less than one livestock unit per ha for up to 10–15 years, mostly with beef cattle, and to some extent with dairy cattle or buffaloes. This time span allows tree roots to break down naturally. After extensive grazing, the grass sward is degraded, but land is considered suitable for cropping (absence of tree roots). Crops cultivated on these deforested plots are destined to be used for human consumption for food (soybean, rice, sugarcane), fibres (cotton) or livestock feed (maize, soybean). In order to sustain such intensive cropping, large amounts of fertiliser are used.

The majority of this land (2 billion ha) is, however, grassland, of which a high proportion is not convertible to arable land. It should be noted that the 290.4 million ha of agricultural land, providing oil seed cakes, crop residues and by-products, are primarily used to grow food for human consumption. On this surface, livestock act as a "recycler" of biomass which would be burnt (in the worst case) or left to rot in the field. These figures show that "only" 279.3 million ha of agricultural land (5.6% of the total agricultural land) are currently used to produce feed for livestock instead of food for humans. If the surface of grasslands potentially convertible to arable land are added, the potential to feed humans directly from arable land would increase by 964.2 million ha and amount to 2564.7 million ha, instead of the current 1600 million ha – an increase of 62%.

However, Schils et al. (2022) warn that converting permanent grassland to arable land entails important environmental costs. Crucial ecosystem services, such as carbon sequestration, water purification and biodiversity, would be lost. Other ecosystem services, such as flood and erosion control, would also decline and CO_2 emissions due to land-use change would increase. Ontl and Janowiak (2017) report that 20% of grasslands worldwide were already converted to cropland, thereby releasing CO_2 and losing organic matter. These trade-offs need to be considered in the current feed/food debate.

Globally, large and small ruminants use the largest tracts of agricultural land devoted to fodder and feed production, as the latter entails large portions of grasslands, as seen previously. Cattle and buffaloes use 51% of the land and small ruminants 39%. Monogastrics use "only" 10% of the land devoted to fodder and feed production (Mottet et al., 2017).

The whole feed/food debate also revolves around the feed or protein conversion efficiency. According to Ferrari et al. (2022), the production of plant protein uses 18 times less land and 10 times less water than animal protein. These findings may not be as simple as they appear. The production of vegetal protein may use less land and for some types less (blue) water, but the nutritional quality is also recognised to be lower than animal-source protein (Day et al., 2022). This raises questions about the relevance of comparing both. Rather than opposing animal-source and vegetal-source protein, one should look at ways to reconcile them, not only on the plate but at farm and landscape level.

As far as the crop rotation allows, feed crops should be replaced by food crops on arable land, while grasslands should remain to sustain herbivores. Eliminating concentrated feed from the diet of ruminants, especially dairy cattle is, however, illusory, if a certain level of production is expected to sustain food security. Optimising diets, feed-use efficiency and crop rotations can, however, lead to a more efficient use of arable land.

Since the scarcest agricultural resource is arable land and ruminant production uses otherwise redundant permanent grassland under rainfed conditions, neither factor plays a major role in the feed/food debate.
It has to be noted that although monogastrics do not use much of the land devoted to fodder and feed production as demonstrated by Mottet et al. (2017), they are nevertheless potentially direct competitors with humans in terms of feeding habits, as they are fed by grains (cereals and legumes).

In the debate about GHG emissions, however, ruminants, which have the potential to not directly compete with humans for feed/food, are incriminated for their methane emissions and relatively low feed-conversion efficiency. This sheds light on one important trade-off. Diminishing (or eliminating) monogastrics would free some land for direct human-feed production, but at the same time important nutrient-cycling functions (conversion of industrial by-products to high-protein food) would disappear. On the other hand, diminishing (or eliminating) ruminants to lower GHG emissions would come at a high environmental cost (in terms of ecosystem services) as highlighted previously.

Mottet et al. (2017) demonstrated that livestock directly compete with humans for food resources to a smaller extent than usually claimed. Indeed, when looking at the current global feed ration of livestock (in terms of dry-matter intake), it appears that 86% of this ration is composed of feed inedible to humans (Fig. 6). The remaining 14% of the diet, mostly grains, compete directly with human feed.

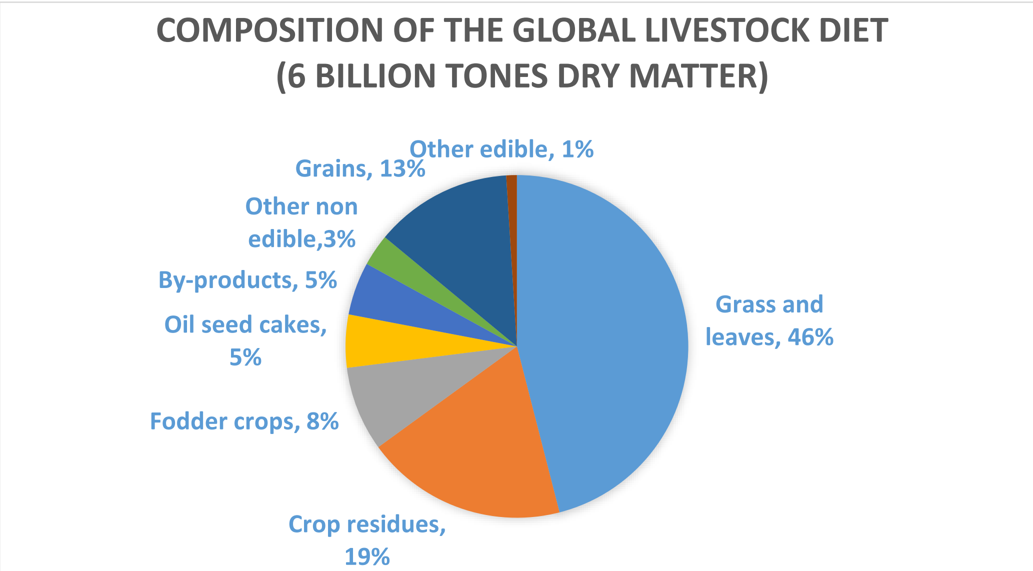

Figure 6. Composition of the global livestock diet (Mottet et al., 2017).

Phelps and Kaplan (2017) argue that a finer analysis of livestock land use needs to be applied.

For instance, they consider the different feeding habits of the various livestock species such as grazing (cattle, buffalo, sheep, yak, alpaca, llama), browsing (goats, dromedaries, Bactrian camels) and foraging (pigs, ducks, reindeer). Such distinctions are important to understand, for example, ecosystem services provided by livestock species and the environmental costs (e.g., overgrazing).

The transition towards low-carbon food systems needs to take into consideration important trade-offs highlighted above: GHG reduction vs water efficiency, and feed/food competition vs ecosystems services. Importantly, the transition needs to account for regional, national, territorial, local, and individual differences in production; availability of, access to, and consumption of LDF; as well as available alternatives. Transition pathways also need to consider all three dimensions of sustainability, and not only the environmental one (Grace et al., 2018).

The following chapters highlight and discuss the contributions of livestock to the social, economic, and environmental dimensions of sustainability, following the four sustainability domains.

In a nutshell: livestock's impact on the environment and climate change

- *Total anthropogenic GHG emissions continue to increase.*
- *Emissions related to food systems increase at a slower pace than emissions from other sectors, thus reducing the former's share over time.*
- *Regional differences highlight the importance of population size and importance of agriculture in countries.*
- *Differences in GHG emissions between the three components of the food system, across regions and countries, show that differentiated approaches to tackle GHG emissions are needed.*
- *Livestock is a large user of agricultural land; however, to a large extent, in areas not devoted to crops or convertible to arable land.*
- *The water footprint of livestock products (per kg, calorie and protein) is often lower than the footprint of vegetal products, when blue water (irrigation) is considered. Blue water will be increasingly used to irrigate food crops, and potentially also pastures, as rainfall will be more erratic and scarcer.*
- *Transformation pathways will need to be tailored to fit regional, country, and territorial realities. There are no universal solutions.*

4. Role of livestock in food systems transformation

Summary of this chapter:
Humankind currently depends on 38 domesticated animal species (20 mammals and 18 avian), from a pool of over 50,000 species. Of the 38 domestic livestock species, five dominate livestock systems worldwide: poultry, pigs, cattle, sheep, and goats. Recent estimations show that livestock products provide an estimated 18% of calories and 34% of proteins consumed worldwide. The provision of animal proteins is covered by cattle (45%) in the form of meat and dairy, poultry meat and eggs (31%), pigs (20%), and sheep/goats (4%).

Trends estimate a growth in meat and dairy consumption worldwide until 2050: at a slower pace in industrialised countries with current high levels of meat and dairy consumption and at a faster pace in emerging economies and developing countries.

It seams reasonable to reduce current meat consumption in countries where the daily intake exceeds the estimated requirements of 100–120 g meat[5] per day, while implementing measures to increase current consumption levels to meet recommended levels in other countries. A lack of LDF in the diet is directly linked to malnutrition and undernutrition.

Globally, livestock represents the third source of income for farmers, after crop and non-agricultural income. It is estimated that livestock production contributes, on average, to 40% of the agricultural gross domestic product. Furthermore, livestock provides essential services to crop production in the form of draught power and manure. The value of this indirect contribution to food security exceeds the value of direct contribution through products (meat, milk, etc.). As the cultural and religious value of livestock, or many other services (contribution to soil fertility, ecosystem services, etc.) are hardly quantified and hence not monetised, they tend to be overlooked or neglected in the narrative about food systems transformation.

It is estimated that grasslands currently hold 20% of the world's soil organic carbon (SOC). Globally, grasslands exhibit a positive carbon balance. This indicates that they receive sufficient biomass to increase or maintain their C stock. Many livestock-related practices currently causing negative impacts on biodiversity can be altered or reversed by keeping livestock but by changing management. Strengthening the positive impact of livestock on rebuilding carbon stocks and biodiversity, e.g. through agroecology, in pastures, grasslands, peatlands and forests therefore needs to be a priority for current and future generations of farmers, researchers, policymakers, and market actors.

4.1 Livelihood and nutrition

4.1.1 Livelihood

Humankind has depended on animals for various inputs and services for millennia. Animals were first taken from the wild through hunting. With the settling and development of agriculture in the Neolithic Age, followed by the domestication of a limited number of animal species between 11,000 and 500 BC, humans changed their behaviour from predation to production (Vigne, 2011). This "*mental revolution*", as Helmer (2008) called it, helped humans to exert control over their environment and its resources – especially food, which was considered the main limiting factor to population growth (Ariès, 2017).

The domestication process, which is thought to have started with anthropophilic and/or commensal species such as the wolf, has intensified over time, moving from the control of animals in nature to keeping them in captivity. With domestication and, later, breeding, humans managed to modify biological properties of animals resulting in major changes in behaviour (tamer animals), morphology (reduction of size, change of coat colours and patterns) and fertility (increased number of offspring).

Similarly, the animal production process started in an extensive manner and intensified over time to reach industrial proportions in landless, large-scale, intensive systems. According to the Domestic Animal Diversity Information System (DADIS) from FAO, humankind currently depends on 38 domesticated animal species (20 mammals and 18 avian), from a pool of over 50,000 species. These 38 species entail 8774 recorded breeds, 6149 mammals and 2625 avian breeds.

[5] Or 100–120 g poultry/meat/fish/seafood/tofu/Quorn/seitan, or 2–3 eggs, or 150–200 g yoghurt or fresh cheese (seré, blanc battu, cottage cheese), or 30 g hard cheese, or 60 g soft cheese, or 200 ml milk.

It is estimated that 647 (7.4%) of these breeds are extinct (565 mammals and 82 avian). Of the 38 domestic livestock species, five species dominate livestock systems worldwide: poultry, pigs, cattle, sheep, and goats.

Besides inputs and services provided to crops in the form of manure and draught power, livestock also provide humans with other crucial products and services such as food, fibres, hides for construction materials, cash, insurance against risks, and other economic and social benefits.

4.1.2 Food and nutrition security

Feeding humans is characterised by three facts: humans are omnivorous, have small stomachs, and high calorie requirements for brain activity[6] (Raichle and Gusnard, 2002).

LDF appears to have been part of hominins' diets for a million years (meat) and thousands of years (dairy). Indeed, strong evidence suggests that meat has been part of the diet of hominins for at least 2.5 million years (Teaford and Ungar, 2000). A recent discovery of prehistoric stone tools, human teeth, and bones of hippopotamus-like animals in Kenya showed that hominins butchered and fed on these animals more than 3 million years ago (Plummer et al., 2023). Recent archaeological excavations in Poland revealed that the processing of milk from cattle, goats and sheep existed in the late Neolithic period, when lactose intolerance was still widespread in Europe (Evans et al., 2023).

It is generally assumed that increased meat consumption is highly correlated with brain and body growth and gut restructuring in *Homo erectus* (Bunn, 2007; Aiello and Wheeler, 1995). However, this "*meat made us human*" theory was challenged by a recent zooarchaeological study by Barr et al. (2022). They examined large, well-preserved archaeological sites throughout East Africa and found no evidence of increased carnivory after the appearance of *Homo erectus* 1.9 million years ago. In any case, it appears that diets most probably shifted throughout time. Using isotope methods to determine the source of protein in the diet, Richards and Trinkaus (2009) showed that Neanderthals living in Europe between 120,000 and 37,000 BP were "*top carnivores*", feeding mostly on large herbivores. The same study also revealed that "*modern humans*" who appeared later on (40,000 to 20,000 BP) also fed on freshwater- and marine animal-protein sources.

In any case, it is undisputed that animal foods provide a significant portion of essential nutrients in the human diet, and do so in high quality, density, and bioavailability. LDF is considered to have a higher biological value than plant-based protein, as the former covers the entire spectrum of amino acids essential to humans and has a higher digestibility (Federal Commission for Nutrition, 2011). Purely plant-based diets show deficiencies in calcium, magnesium, potassium, zinc, and vitamin B12, which need to be compensated by food supplements (Keith and Gonder, 2021). LDF has the advantage of being nutrient-dense and having nutrients which are absent in plants (e.g., vitamin B12). The bioavailability of certain nutrients (e.g. iron, zinc and vitamin A) is also higher in LDF than in plant-based food (Grace et al., 2018). LDF has iron with a high proportion of heme, which is absent in iron found in plants. In addition, LDF does not have any iron inhibitors, but plants do. These specificities make LDF suitable food to lower risks associated with anaemia caused by iron deficiency. Similarly, plant-based food possesses inhibitors, such as phytic acid, for example, which prevent zinc absorption. These antinutrients are high in grains, seeds, nuts, and pulses.

[6] The brain is about 2% of total body mass, but requires 20% of the body's total energy requirements.

LDF also contains unique substances, such as carnosine, taurine, and creatine, which are absent from plant-based food. These substances play a crucial role in memory, cognition, cardiovascular health and immunity, among others (Beal et al., 2022).

Mettler et al. (2010) also point out that the higher protein density and protein quality of animal protein sources is ideal for maximum activation of muscle protein synthesis, which is especially important in the elderly (Reid-McCann et al., 2022; Gorissen et al., 2016).

Livestock products are therefore considered crucial for human nutrition at specific life stages, when needs are high and intake is limited or reduced; namely for pregnant women and infants in the first-1000-days window, and elderly people (GAIN, 2020). This means that meat consumption makes sense for nutritional reasons, but that vegetarian or vegan nutrition can also be promoted; provided that plant ingredients are well combined (e.g. cereals and legumes) and food supplements are available (Federal Commission for Nutrition, 2011), especially during pregnancy (SSN, 2018).

Recent estimations show that livestock products provide an estimated 18% of calories and 34% of proteins consumed worldwide (FAO, 2017). The provision of animal proteins is covered by cattle (45%) in the form of meat and dairy, poultry meat and eggs (31%), pigs (20%) and sheep/goats (4%) (Mottet et al., 2017). The global consumption of meat and dairy products has grown continuously over the past 50 years and is projected to do so until at least 2030 (OECD and FAO, 2022). In 2019, the world's average consumption of meat was 34.1 kg/capita/year, equivalent to 93 grams per day. However, LDF consumption has huge regional discrepancies. Meat consumption is highest in industrial countries with a high income – 69 kg/capita/year – and lowest in developing countries – 26.2 kg (OECD and FAO, 2022). In Switzerland, the consumption of LDF slowly but steadily decreased from 51.8 kg/capita/year in 2007 to 47.4 kg in 2022. For the same period, the consumption of milk and dairy products decreased from 260.7 kg[7]/capita/year to 238.6 kg (OFS, 2023).

A more detailed look at consumption figures in Switzerland, however, shows that the consumption of pork, veal, mutton, horse, and goat meat is decreasing while the consumption of beef is stable, and the consumption of poultry meat and eggs is increasing. Similarly, the consumption of fresh milk has drastically decreased since 2007, while, in contrast, the consumption of cheese increased. Trends and projections show that the worldwide consumption of meat and dairy will continue to grow, but at a slower pace, in industrialised countries until 2050, while it will grow at a faster pace in emerging economies and developing countries with currently lower consumption levels (OECD and FAO, 2022). Reducing current meat consumption in Switzerland and elsewhere by 50–70% would make sense from a nutritional perspective, as consumption currently surpasses daily requirements (estimated at 100–120 g meat[8] per day; SGE/SSN/SSN, 2023).

[7] Milk and yoghurt shown as milk equivalents, cheese shown in kg.
[8] Or 100–120 g poultry/meat/fish/seafood/tofu/Quorn/seitan, or 2–3 eggs, or 150–200 g yoghurt or fresh cheese (seré, blanc battu, cottage cheese), or 30 g hard cheese, or 60 g soft cheese, or 200 ml milk.

4.2 Economic role and other values

4.2.1 Livelihood and economics

The role of livestock as economic agents is very diverse. Animals and their products can be sold, exchanged, bartered, given, or lent for a wide range of considerations such as cash, loans, credit, savings, guarantees, insurance, security, asset building, risk spreading, social bonding, and so on. The number of people depending directly on livestock for their livelihood and food security is estimated at appr. 1 billion (Robinson et al., 2014).

On average, globally, livestock contributes to 15% of the smallholders' farm income (between 3–37%, depending on the country). Globally, livestock represents the third source of income for farmers, after crop and non-agricultural income.
It is estimated that livestock production contributes globally, on average, to 40% of the agricultural gross domestic product (between 15–80%, depending on the country). It must be emphasised that this share is higher, on average, in developed countries (40%) than in low- and middle-income countries (LMIC) (20%) (FAO, 2018b).

Livestock, especially small stock, is often considered an important asset for women in developing countries (especially the poorer ones), allowing them to access cash. It is estimated that female livestock keepers account for two thirds of the 600–800 million poor livestock keepers (FAO, 2012). Indeed, in many countries, women have no access to collateral, especially land titles, and therefore no access to credits and loans (FAO, 2013). Livestock, as collateral but also as an economic agent, is a means for women to gain economic and social power. In 2015, the International Livestock Research Institute (ILRI) developed the Women's Empowerment in Livestock Index (WELI) to determine which livestock-related interventions impact women, and how (ILRI, 2015).

One dimension of livestock which is often overlooked, as it is difficult to capture in monetary terms, is the fact that it allows farmers to mitigate risks on their farm. Livestock contributes to the diversification of the production portfolio and can be destocked in case of hardship (crop failure, drought, etc.) to meet a family's current or unexpected expenses. Livestock also offers avenues for system resilience – resilience being understood more as a transformative process rather than "*bouncing back*" to the initial stage after a crisis (Hodbod et al., 2022). Pastoralism – one of the oldest forms of livestock rearing – is considered particularly resilient by essence. Indeed, its persistence over time (more than 10,000 years) and throughout all ecological zones[9] shows its adaptation and transformation capacities, resisting numerous and various natural and human-made shocks and hazards (Manzano in Hodbod et al., 2022).

4.2.2 Trade

FAO (2022b) stated, "*Trade is a vital part of agrifood systems, as it ensures the flow of agricultural commodities across the globe and especially to countries that may not produce enough of these commodities to meet domestic demand*." Livestock contributes to household livelihoods and a country's economics through trade; either as live animals, for breeding or slaughter, or as products, raw or processed.

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[9] Arctic tundra (reindeers), Eastern, central and southern Europe (cattle, sheep, goats), sub-Saharan Africa (sheep, goats, cattle, dromedaries), Central Asia (sheep, goats, Bactrian camels, yak, horses), the Himalaya (yak, cattle, horses, sheep, goats), South Asia (dromedaries, sheep, goats, horses) and the Andean regions (camelids).

From 2005–2021, livestock ranked third (in monetary value) after fruits and vegetables and cereals in global trade (FAO, 2022b). Meat prices rose in recent years due to epizootic diseases, such as Highly Pathogenic Avian Influenza (HPAI) and African Swine Fever (ASF), and increasing prices of inputs, such as feed. For the same period, the top food net-exporter countries were Brazil (beef, soybean, sugar), New Zealand (milk powder, beef, mutton) and Spain (olive oil, pork). Top importers of livestock products were China (beef, soybean, maize, palm oil), Japan (beef, soybean, maize, rapeseed) and the UK (chicken, beef, wine). These global figures, however, hide the great diversity of exchanges across commodities, regions, and countries. Figure 7 shows the predominance of the Americas, Europe, and Oceania in the export of livestock commodities (and cereals) and the importance of Asia as a "consumer" of these goods. Pork is the largest traded meat, in quantity, followed by poultry, beef, and lamb/mutton.

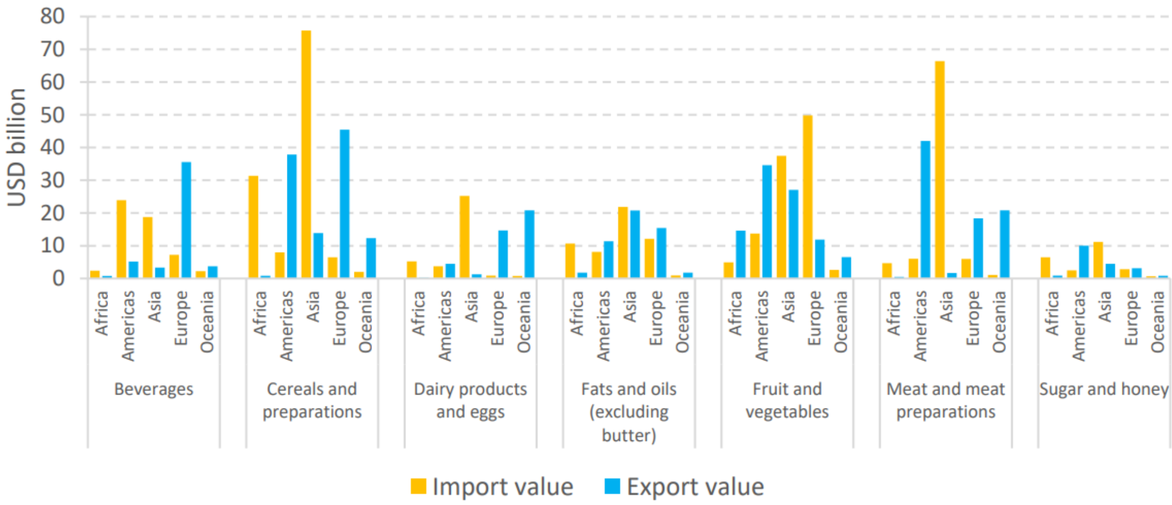

Figure 7. Food (excluding fish) imports and exports by main categories and region (2021) (FAO, 2022b).

4.3 Cultural value and religion

The importance of livestock for humans goes beyond the mere provision of goods (e.g. meat, milk, fibre, eggs) and services (e.g. manure and draught power for crops). It also entails a mental and spiritual dimension. Throughout the ages, humans have projected their aspirations, fears, and fantasies on animals (Beeching, 2008) and this has materialised in religion, culture, beliefs, and taboos, for example. The cultural and religious importance of animals, especially livestock, should not be overlooked in the narrative about transformation of food systems.

Many livestock species are still raised and consumed in regions where they were domesticated millennials ago (e.g., poultry in China and Southeast Asia) and remain an important part of the culture. The consumption or abstinence of LDF follow a wide range of rules and taboos in all religions and philosophies. Specific types of LDF are consumed or shunned for special events, such as weddings, birth ceremonies, benedictions, funerals, visits, etc. Most religions and philosophies also have different rules regarding the consumption of LDF; pork is shunned in Islam and Judaism, and cattle meat in Hinduism, to name the best-known examples.

Interestingly, while killing animals is forbidden in Buddhism, eating meat and animal products is not shunned, except for monks and nuns. In China and Vietnam, many people still follow a diet inspired by Taoist principles, with food ranging from cool and cold (yin), to neutral, warm and hot (yang). Most milk products and eggs, like many vegetables, belong to the fresh (yin) category, while most meat, spices and herbs belong to the yang category. Pulses and grains are considered neutral food. The consumption of food categories varies according to the lunar calendar, and also health status, gender, age, etc. In Ethiopia, Orthodox Christians fast for 180 days a year during which animal-source food is forbidden (d'Haene et al., 2021).

Eating is also strongly linked to specific events in life. In numerous countries, pregnant and lactating women are subject to numerous taboos related to the consumption of LDF, but also other foods such as fruit or vegetables. Food habits are not only related to the country, ethnic or religious group, gender etc. but also to personal history and individual preferences. These habits can be more deeply ingrained than often thought and provoke resistance to change. Cultural habits in general change slowly (Vranken et al., 2014).

The religious or cultural function of livestock goes beyond food habits. In many cultures, livestock is sacrificed for gods, spirits, and deities. Festivals revolving around livestock developed over time, such as corrida (Spain, France), bull fighting (H'mong community in Laos), cow fighting (Alps), cock fighting (several countries in Asia, Africa and Latin America), bull races (Indonesia), buffalo races (Vietnam), camel races (Middle East), and rodeos (the Americas). Many of these traditions may increasingly be considered an expression of male dominated societies and archaic, but for the communities they represent living traditions, and a patrimony, and thus involve many more dimensions than the "show" seen by outsiders.

Similarly, the function of livestock as an object of prestige in many regions of the world must not be underestimated. Holding large herds may be seen as an external sign of prestige, even if the animals may be underfed. Indeed, a large herd reflects the owner's wealth and ability to build assets as a form of insurance, which can be destocked in times of hardship.

The cultural or religious value of livestock, as well as many other services (contribution to soil fertility, ecosystem services, etc.) are rarely quantified and are not monetised. These contributions therefore tend to be overlooked or neglected in the narrative about food systems transformation. Ignoring these factors by reducing livestock to mere purveyors of food, cash, or contributors to GHG emissions is a gross simplification of the farmers' reality and a truncated view of sustainability.

4.3.1 Human–animal relationships

The multimillennial common history and relationship between humans and animals is reflected in numerous testimonies, such as parietal, statuary or, more recently, folk art. The impact of animals – in general, and specifically livestock – on people's daily lives can take many forms: as pets, as representation of deities, as figures in comics, or more prosaically in food, clothing, transport, etc. Depending on these roles and the relationship, animals are objects or subjects of humans' lives. Usually when the relationship between animals and humans is close, animals become subjects and are not eaten (Museum der Kulturen Basel, 2022).

However, farmers also often develop a close bond with animals ultimately destined for slaughter. This ambivalent relationship is often difficult to understand for people outside farming communities; it is part of the "social contract between farmers and livestock".

Farmers traditionally raise, feed, and nurture their animals to ultimately sacrifice them, while animals trust humans to raise, feed, and nurture them (Armstrong Oma, 2010). Armstrong Oma disagreed with the theory proposed by Ingold (1994) that the relationship between hunters and prey was based on trust, while the relationship between livestock keepers and their animals was a relationship of domination and slavery. Armstrong Oma argued that, on the contrary, it was the relationship between humans and livestock which was based on mutual trust. Knight (2005) stated, "*Domestication does provide the temporal and spatial conditions for human–animal intimacy to emerge*." The intensification of the human–animal relationship resulted in new human behaviours towards animals; for instance, animals being kept as pets (Vigne, 2011). The physical proximity and frequency of interactions also resulted in an increased exposure to zoonotic diseases.

The human domination over animals, in all forms, is being increasingly challenged not only by a minority of animal welfare and animal rights activists, but by citizens and consumers. Animals, as sentient beings, are increasingly perceived as equal to humans. First evidence of notions related to animal protection and animal welfare date back to the 17th century. In Switzerland, people from higher society were inspired by the British model and founded animal protection associations in Bern in 1843 and in Zurich in 1856, with a rather anthropocentric vision. In 1893, ritual slaughter was forbidden in Switzerland. In 1973, Switzerland drafted a Federal Law on animal protection, one of the most restrictive in the world, regarding livestock keeping and animal welfare. The Law application was issued in 1976 and has been enforced since 1981 (Lüthi et al., 1991).

In 1999, the status of animals in the Swiss Civil Code was modified and animals are no longer considered as "*things*" (Assemblée fédérale, 1999). The animal welfare position has a crucial difference to the animal rights position – the former implies that using animals is morally right (or not wrong), while the latter implies that using animals is morally wrong. From there, the animal welfare position accepts or tolerates a series of human behaviours (e.g., detaining, killing animals) which are not tolerated by proponents of the animal rights position. Stopping the exploitation of animals in whatever form it may take (food, fibre, transport, leisure, etc.) is at the heart of the anti-speciesism ethos.

However, the boundary between animal-welfare and animal-rights discourse is becoming increasingly blurred. Similarly, the discourse on the environmental impact of livestock production is becoming increasingly mingled with ethical considerations related to animal rights. This is reflected in the narrative "eat no animal products and you will do something good for the planet." In her advocacy that "*if you want to save the world, veganism is not the answer*", Tree (2018), however, demonstrated in an empirical way why both narratives cannot be united.

4.4 Human and animal health

Human and animal health are closely related in various ways. As already seen, the consumption of LDF is crucial in specific time windows to guarantee physical health and ensure cognitive development. A lack of LDF in the diet is directly linked to malnutrition and undernutrition (WHO, 2023). On the other hand, the overconsumption of LDF can be detrimental to health. Diets rich in LDF, especially in red meat, are associated with a higher risk in diabetes, cardiovascular diseases and cancer – all non-communicable diseases (NCD).

Exposure to animals and animal products also entails specific health-related issues. Animals, humans and ecosystems interact closely. Wild animal populations often act as a reservoir for existing or emerging diseases affecting domestic animals and/or humans.

Human activities and domestic animals encroach on ecosystems and habitats hosting wild animal populations, therefore increasing interface and exposure to pathogens. The World Organisation for Animal Health (WOAH) estimates that 60% of existing pathogens affecting humans have a wild or domestic animal source and 75% of emerging pathogens affecting humans are of animal origin (WOHA, 2022).

4.5 Energy sector: draught power, circular economy, biogas

In the past, mixed systems, which integrate crops and livestock production, were widespread, but both components were decoupled after specialisation, which created more intensive forms of farming. Decoupling components of agricultural production led to environmental, economic, and social issues, such as soil erosion, increased use of synthetic fertiliser and pesticides, nutrient accumulation in soil and water, GHG emissions, and increased risks for farmers. Recoupling both components on farms and at territorial level is one means to close nutrient and energy cycles and improve the overall efficiency in the system (Garrett et al., 2020).

Livestock contributes two crucial services and inputs to mixed systems: **draught power** and **manure**. Draught animals represent one of the three energy sources used in crop production, along with human power and fossil fuel- and engine-powered machines.

4.5.1 Human power

Cultivation of land by hand (hoe) is the oldest form of land cultivation and dates back to the inception of agriculture. It is currently still done in situations where animals and/or machines cannot be used for various reasons: high initial investment costs for draught animals or tractors, presence of trypanosomiasis in the *tsetse* fly belt, access to land to feed work stock or access to energy to power engines, small or sloping arable land plots, etc. Twenty years ago, approximately two-thirds of the world's farmers still cropped their arable land by hand: 80% in Africa and 40–60% in Asia and Latin America (Mazoyer and Roudart, 2002). According to the authors, only 15–30% of farmers in the Global South used draught animals for cropping activities and less than 5% used engine-powered machinery. The authors estimated that cultivating 1 ha by hand required one human per year, while one draught animal could cultivate 5 ha/year.

4.5.2 Animal power

In Western countries, including Switzerland, most cropping activities, as well as transport of humans and bulky items, were formerly done by animals until they were replaced by engine-powered machines after World War II. In Switzerland, cattle (cows, bulls and oxen) were used more frequently than horses to cultivate cropping fields and pull carts. Horses were mainly kept by more affluent farmers. Cattle were bred as triple-purpose animals: for milk, meat, and draught power. The breeding purpose for Simmental and Fleckvieh breeds – dominant in cropland areas – was proportioned into 55/25/20% for milk, meat, and draught power, respectively, while the Braunvieh – found more often in mountainous areas with less cropland – was 60/30/10% respectively (Moser, 2015).

With the invention of the steam engine and later the tractor, farmers no longer needed cattle or horses to do heavy, labour-intensive tasks. People stopped seeing animals "at work" and these images are now confined to old photos and archive materials. This shift also affected an important connection; namely the strong bond forged during training and work between the farming families and their working animals (Moser, 2015).

4.5.3 Engine power

To some extent, steam engines (but mainly tractors) allowed farmland to be cultivated at a much faster pace than with animals, and with much less effort; not only for the animals but also humans. Engine power counterbalanced the decrease in farming manpower, so that the remaining farmers could continue to feed the increasing resident population. In Switzerland in 1905, the ratio of farm-to-resident population was 1 to 14, while in 2021 it was 1 to 178 (OFS, 2022). Interestingly, in 1900, Switzerland had a very low self-sufficiency level in grains despite more people being active in agriculture (Mauch, 2020).

The increase in comfort and efficiency by switching to engine power was rendered possible only thanks to the use of fossil energy (coal for steam-powered machines and diesel for tractors), a much less sustainable source of energy than plant material used to "fuel" draught animals. Nowadays, in Western countries, the transition to more-sustainable forms of energy (biodiesel, renewable energy for electric engines) is timid and limited by the lower market for such machines compared to the market for private cars. In Western countries, some farmers and foresters never stopped working with animals, or started again, mainly for environmental reasons. This, however, involves a small minority of farms, with niche or high-value production (e.g. producing vegetables, orchards, vineyards) and small plots of land (e.g. micro farms).

While working farm animals have largely disappeared from daily life in industrialised countries, they remain a crucial asset in most countries of the Global South. Unfortunately, the number of draught animals used for crop cultivation worldwide is not well documented. In 1982, the number was estimated at about 400 million (Barwell and Ayre, 1982). Nowadays, draught animals are mostly found in Asia, Africa, and Latin America, on farms with small land plots and/or where engine-powered machines are unaffordable. In India, it is estimated that 65% of arable land is cultivated by animals, mostly zebu cattle (*Bos taurus indicus*) (Mota-Rojas et al., 2021).

Draught animals are not only used for ploughing, puddling or harrowing the fields, but also for hauling bulky materials, such as matter destined for crops (e.g. manure) and crops destined for humans (e.g. rice bundles, sugarcane, cassava, etc.). *Bovidae* (cattle, zebu, yak, buffalo), *Equidae* (horses, donkeys, and mules), and *Camelidae* thereby provide an important **indirect contribution to food security**.

Draught animals thus represent a "*middle force*" that results in an increase in both labour and land productivity (Ellis-Jones and O'Neill, 2000). A study comparing practices of two distinct Amish communities and modern farms in the USA showed that draught animals produce dairy in a more energy-efficient way than with the tractor, but in a much more labour-intensive way (Joannon et al., 2022). The benefit of animal draught power coupled to manure is estimated to be as equally important or even to outrange the production of animal-source food in the agricultural system (Mota-Rojas et al., 2021).

4.5.4 Animal waste for energy

Beside draught power, manure is one of the other crucial elements of mixed systems. The integration of livestock into the cropping system enhances crop yield and soil health by increasing synergies between the elements of the system (Bansal et al., 2022).

Animal waste (manure, slurry) can be used as raw material to generate clean, renewable, and affordable energy in a closed system, called "The Clean-Energy Livestock Nexus" by FAO (2018b). Livestock converts biomass, grown via solar energy (photosynthesis), into valuable products (meat, milk, fibres) and manure. The latter is used to generate biogas.

Solid waste can be used as a raw material for vermicomposting, biochar, and compost. Methane generated by biogas can be used as direct energy for cooking, cooling devices or generating electricity. The carbon dioxide fraction of biogas can be used to produce biomass (e.g. algae) which can in turn be fed to livestock or used as energy (algae oil) (FAO, 2018b).

Europe, China and India paved the way for biogas installations, including for smallholder livestock farmers. In Switzerland in 2020, it was estimated that the 100+ biogas installations produced 400 gigawatt hours (PSI, 2020). Globally, solid data on the use and treatment of manure to generate energy are lacking, but opportunities for improvements are estimated to be immense (FAO, 2018b); however, FAO warns of an important trade-off, namely the danger of putting too much weight on manure as an energy provider, which jeopardises its role in fertilisation, crop production and ultimately food security.

4.6 Soil health, carbon stock and nutrient cycles

4.6.1 Soil health

Soils are the natural capital to ensure life on Earth. Soil science has a long history in describing soil genesis and its functions in agriculture. The importance of soils and soil health for food security and sustainable agriculture was acknowledged in recent research. Discussions about soils being able to stock carbon, and their function as biodiversity habitats, gain momentum in current debates on climate change and biodiversity preservation.

The decreasing carbon stocks in agricultural land has become a global concern. Intensive agricultural practices and mechanical soil preparation, and the intensive use of synthetic fertilisers, pesticides and monocultures have detrimental effects on the structural and microbial soil environment, particularly on the organic soil carbon content. According to the FAO (2017), soils represent the largest terrestrial organic carbon reservoir. The carbon-holding capacity depends highly on geophysical conditions, the climate and, to a large extent, land use.

The highest levels of carbon stocks are found in the Northern Hemisphere in peat soils exposed to permafrost. FAO's carbon map indicates regions with higher and lower carbon contents, which indicates correlations to land-use types and geophysical conditions of soil types. Areas under less-extensive farming practices – like permanent and dense plant cover such as pasture and grassland, silvo-pastoral and agropastoral farming systems – indicate higher carbon stocks compared to land use under intensive crop and horticulture-based farming systems.

Soils, through the carbon sink capacity, play a critical role in regulating climate and mitigating climate change through trade-offs between GHG emissions and carbon sequestration (FAO, 2017). Maintaining and rebuilding carbon stocks in agriculture, e.g. through agroecology, and pasture, grassland, in peatlands and forests is therefore a crucial role for current and future generations of farming communities, researchers, policymakers and market actors.

The beneficial effects of crop rotations, perennial cropping systems including agroforestry, permanent and rotational grass- and pasturelands, green manure, organic manure application, biochar, and compost as effective measures to sink carbon in soils has been amply demonstrated.

4.6.2 Grasslands and CO_2 sequestration

As previously mentioned, grasslands occupy 3.2 billion ha, which represents 25% of Earth's ice-free surface or 68% of agricultural land (FAO, 2021).

In Europe, permanent grasslands occupy 34% of the agricultural area (Schils et al., 2022) and in Switzerland 70%[10], equivalent to 24% of the country's total area. In Switzerland, arable land accounts for only 27% of the agricultural land and permanent crops 3% (OFS, 2021). In Switzerland the decline of the agricultural area between 1985 and 2018 is equivalent to twice the surface of Lake Geneva.[11]

In the lowlands, agricultural areas are encroached on by construction, and in altitude areas by forests. The small and declining arable land area, and the fact that numerous policy measures restrain farming activities (e.g., on compensation areas and buffer zones) or limit farming intensity in high altitudes (no mowing, no fertiliser), result in relatively intensive agricultural practices on the remaining arable land (Pazúr et al., 2021). A recent study showed that in Switzerland in the past 20 years, agricultural intensification took place in all agroclimatic zones[12] due to the increase of settlements and the decrease of agricultural land (Achermann et al., 2023).

Grasslands can be split into three main categories: natural, semi-natural, and improved grasslands. Natural grasslands are shaped mostly by climate, fires and wildlife and to some extent also by livestock, while semi-natural and, especially, improved grasslands are shaped by livestock (grazing) and humans (mowing, cutting, ploughing, sowing) (Bengtsson et al., 2019). Although grasslands support the livelihoods of only 10% of the world's population (FAO, 2005), they provide essential and vital ecosystems services for the planet and its inhabitants. Bengtsson et al. (2019) list six ecosystem services: 1) provision of animal feed, 2) biodiversity, 3) climate regulation, 4) water purification, 5) cultural value, and 6) erosion and flood control. In their systematic review, the authors found that grasslands often performed better than forests in terms of cultural value and biodiversity, while forests performed better in terms of erosion and flood control. Both forests and grasslands showed evidence of climate regulation, water purification and carbon sequestration.

A meta-analysis conducted by Liu et al. (2022) on the economic value of grassland ecosystem services assessed that multiple grasslands provide a wide variety of ecosystem services that contribute to human wellbeing. The annual economic value per hectare ranges from USD 3955 for semi-desert grasslands to USD 5466 for tropical grasslands. Among the different types of ecosystem services, the highest value was reported for regulating services which were rated eight times above the value of food supply. The meta-analysis indicates an economic value of global grasslands at more than USD 20.8 trillion, which exceeded 17% of the global GDP in 2017.

The role of grasslands in carbon sequestration as an ecosystem service is becoming increasingly prominent in the discussion about CO_2 removal from the atmosphere. A study from UC Davis University showed that grasslands provide better CO_2 sequestration than forests in drought- and fire-prone California (Dass et al., 2018). Grasslands, like other types of agricultural land, can be a source (emitter) or a sink (stocker) of carbon. This depends on a wide array of factors such as management practices, soil properties (clay content, pH) and climatic conditions. Soil carbon stocks tend to be higher in temperate regions than in arid and semi-arid zones. Harmful or invasive management practices such as overgrazing or conversion to arable land tend to release carbon, while proper grazing management tends to stock carbon.

[10] Alp grazed pastures (32.8%), natural meadows (23.1%), local pastures (12.3%), alpine hay meadows (1.8%)
[11] 580.03 km^2
[12] The Plateau, mountain zone 1 to 3 and mountain zone 4 in the Alps.

According to Thanawat Tiensin, Director of FAO's Animal Production and Health Division, assessing the current state of grassland systems and their potential to sequester carbon in the soil is key to better understanding the benefits or ecosystem services of grassland for food security, biodiversity conservation and climate change mitigation. In 2023, FAO published the first global assessment of soil carbon in grasslands (FAO, 2023). This report provided a baseline of soil organic carbon (SOC)[13] stocks estimated in grasslands and calculates the potential of grasslands for carbon sequestration. In 2010, grasslands stocked 63.5 megatons (MT) of carbon in the 0–30 cm soil layer. With 53 tonnes C/ha, unimproved grasslands (equivalent to semi-natural habitats) exhibited a slightly higher SOC stock than improved grasslands (50 tonnes C/ha). The report estimated the C sequestration potential of grasslands at 0.3 tonnes C/ha/year if correct management practices are applied.

It is estimated that grasslands currently hold 20% of the world's SOC. Globally, grasslands exhibit a positive carbon balance. This indicates that they receive sufficient biomass to increase or maintain their C stock. Carbon stock balances, however, fluctuate greatly across regions. Grasslands with negative carbon balance are found in East Asia, Central and South America, and Africa south of the Equator. These regions exhibit higher anthropogenic stresses, combined with harsher climatic conditions. Negative trends of carbon loss can be reversed thanks to better grassland management, especially through rotational, planned or adaptative grazing measures and controlled stocking rates. The highest potential to increase SOC sequestration is found in sub-Saharan Africa and South Asia on a per hectare basis (0.41 and 0.33 tonnes C/ha/year, respectively), followed by Oceania, North America and East Asia. According to Ontl and Janowiak (2017), carbon stocks in grasslands are higher in temperate climates than in tropical climates.

4.6.3 Soil fertility

Nitrogen (N), phosphorus (P) and potassium (K) are the three main nutrients indispensable to crop growth. Imbalances in the supply of these nutrients will impact crop yields, the environment and climate change. According to Idel (2016), the most fertile lands, now the cradle of cropping activities, evolved over thousands of years of grazing by ruminants (aurochs, bison, buffalo, llama, etc). If so, the role of animals in soil fertility, and, therefore, indirectly to food and nutrition security, is older than the domestication process. Interestingly, domestic livestock is now incriminated for its negative impact on soil, water and air quality through excessive nutrient release.

Excessive fertiliser use, mainly N and P, driven by unsustainable agricultural activities, undermines the stability of Earth's ecosystem (FAO, 2022b). The cropland nutrient budget (FAO, 2022c) indicates a global excess of 85 MT of nitrogen (54 kg N/ha), 7 MT of phosphorus (4 kg P/ha) and 12 MT of potassium (7 kg K/ha). Surpluses of phosphorus and potassium reduced over time, while surpluses of nitrogen continue to rise globally. However, this global picture hides regional differences. Nitrogen surpluses were visible in all regions, with the largest found in Asia and the smallest in Africa.

Two regions showed deficits in nutrients: Africa in phosphorus and potassium and Oceania in potassium. All other regions showed a surplus in potassium and phosphorus at varying degrees.

[13] The carbon held within the soil that is measurable, expressed as a percentage by weight (g C/kg soil).

In all regions, synthetic fertiliser contributed the largest share of applied nitrogen (and therefore excesses) (Fig. 8).

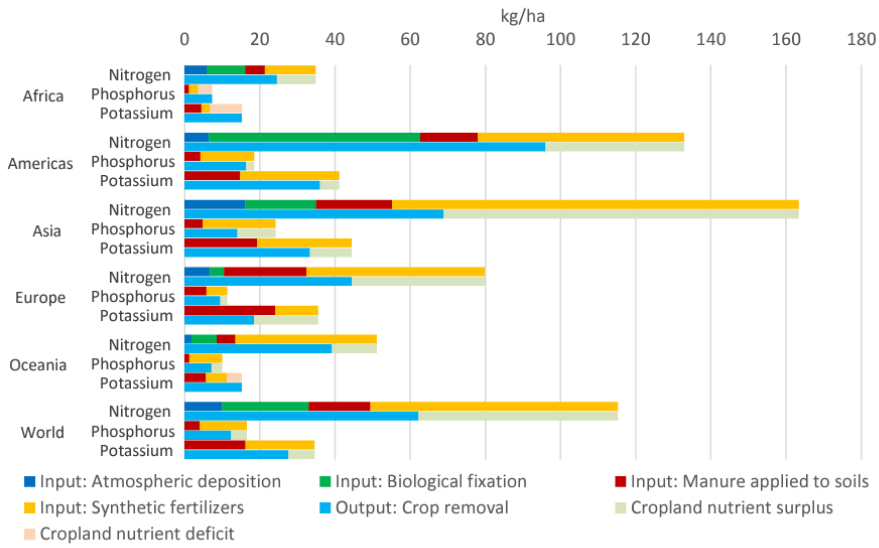

Figure 8. Crop nutrient budgets by regions and 2011–2020 nutrient average (FAO, 2022c).

Data pertaining to global manure production and use is scarce. According to FAOSTAT, manure provided 46 MT nitrogen globally in 2020, with Asia the biggest contributor and Africa the smallest contributor for all three manure-based nutrients (NPK). In none of the regions can organic sources of nutrients, such as atmospheric deposition, biological N fixation or manure applied to soils, meet the demand for nitrogen from crops. The Americas report the highest N input from biological fixation, which is correlated to the high amounts of soybean.

In their study on global animal production and nitrogen and phosphorus flows, Liu et al. (2017) claim that the annual amounts of N and P produced by animals is similar to produced synthetic N and P fertilisers. They also argue that the use of animal-based N and P and its accessibility to plants is ineffective, and the use efficiency level ranges from 5–45%. The N and P efficiency level depends strongly on farms' manure management practices and varies greatly from country to country and farm to farm. Industrialised countries can often count on manure and synthetic fertiliser management policies and law enforcement, which are often absent in low- and middle-income countries (LMIC).

Sustainable agriculture and agroecological principles, promoted among others by the FAO, generated increased attention and interest on the multifunctional aspects of soils and the physical, chemical and biological dimensions that contribute to soil health and fertility. The results of a randomised field trial (the DOK trial; Mäder et al., 2002) with a seven-year crop rotation in Switzerland, which has been running since 1978, proved that the most important indicators for soil quality – soil organic matter, microbial biomass and mycorrhiza – react strongly, positively, to the application of fresh and composted manure while herbicide and pesticide treatments had only a minor differentiation effect (Fliessbach et al., 2007).

In Switzerland, the main issues pertaining to soil health are: soil sealing, erosion, compaction, SOC loss, peat degradation, soil biodiversity loss, contamination, low nutrient use efficiency, N_2O and CH_4 emissions, and suboptimal water balance (Heller et al., 2021).

Regarding soil nutrient balance, the latest estimates at national scale showed a net N, P and K surplus. According to a policy evaluation study, regional problems exist mainly in arable areas (nitrate leaching) and in regions with high animal densities (ammonia emissions, eutrophication of soils and water bodies). At plot level, N efficiency-sustainability dilemma was identified. To increase nutrient use efficiency (NUE), balanced farm nutrient budgets are central to the reduction of excess nutrient levels and losses.

In their global assessment of manure management policies and practices, Teenstra et al. (2014) concluded that increased awareness, conducive policies, access to finance and better farm practices were needed to better value livestock manure, increase NPK fertiliser efficiency, and drastically reduce negative impacts on environment and biodiversity. Integrated farming systems are frequently livestock-dependent, a source of livelihood for the majority of farmers worldwide, and contribute substantially to global food and nutrition security.

4.7 Landscape and biodiversity

4.7.1 Landscape

Wild grazing animals contributed substantially to building carbon- and nutrient-rich soils of vast grazing lands in different climate zones which are currently the "bread baskets" of our civilisations. Since the emergence of agriculture millennials ago, farmers shaped landscapes through their farming activities, ranging from pastoralism to crop cultivation and sedentary livestock production. To produce food, some for themselves and mostly for others, farmers interact with all components of the ecosystems: soil, water, air, climate and all their constituents. As soberly expressed by Cunfer (2005), "*farmers spend their lives managing natural systems to achieve human ends*." To what extent interactions become intersections, interferences and interventions is the question at the heart of sustainability and planetary boundaries.

Until the 19th century, the landscape in European temperate zones was strongly characterised by endless pastures. Herds of cattle, which were mainly kept communally, therefore had the strongest impact and influence on landscape. These pastures were characterised by a very high diversity of plants; for example, numerous orchid species which are nowadays threatened (Bucher et al., 2016). The dung of grazing animals was particularly important for the settlement of insects, and benefited numerous bird species.

In the course of the 19th century, large parts of cattle pastures were converted into arable land or into mowing meadows, and the growing population and increasing industrialisation required more settlement areas. Already by the end of the 19th century, this led to landscape transformation and a strong decrease in biodiversity. Drainage of grazed wetlands and conversion to arable land and vegetable farming also led to a decline in biodiversity (Kapfer, 2022). In the USA, large stretches of the Great Plains – where the buffalo, a wild ruminant, grazed in the millions[14] – were converted to agricultural land, thus destroying a rich biodiversity. Without going as far as Cunfer (2005), who said "*plowing is the ecological equivalent to genocide*", it is indisputable that natural or extensively managed grasslands host a much richer biodiversity than croplands. The large majority of the Great Plains is still covered by pastures, not untouched as they are grazed by cattle, but host to a rich floristic and faunistic diversity (Cunfer, 2005).

[14] Estimated at 30 to 60 million by WWF.

4.7.2 Biodiversity

All human activities have an impact on biodiversity. The negative impact of livestock on biodiversity was highlighted extensively by Steinfeld et al. (2006) in their publication *Livestock's Long Shadow*. Livestock's impact on biodiversity can be direct; for instance, through overgrazing or undergrazing of pastures, or oversupply of fertilisation. These practices all lead to changes in flora and fauna, above and below ground. Impacts can also be indirect, such as, for example, land-use and habitat change caused by deforestation to grow feed crops or pasture or acidification of forests, water and land caused by nitrous oxides. The impact of livestock on biodiversity is often a question of management, with stressors and benefits often being "*two sides of the same coin*" (FAO, 2018b).

Livestock can therefore be responsible for habitat destruction and occupation or habitat creation and maintenance, landscape fragmentation or landscape connectivity, habitat destruction or restoration, GHG emissions or C storage, spread or control of invasive species, and competition with large mammals or as a keystone species (FAO, 2018b). FAO demonstrated that many livestock-related practices causing negative impacts on biodiversity can be altered or reversed, **by keeping livestock but by changing management**, to ultimately benefit biodiversity. Such findings were already mentioned by Niedrist et al. (2009) in the context of the European Alps. The authors showed that management of land (including pastures) had a stronger effect on plant biodiversity than site specificity, although the latter also played a role. Intensively managed land, as well as land abandonment (e.g. removing animals from pastures) strongly, negatively, affected the number and types of plants. Niedrist et al. (2009) "*found the highest number of species on unfertilised, sporadically mown alpine meadows*".

In Switzerland, agricultural policy measures promote the preservation and expansion of extensive grazing as an efficient biodiversity promotion measure. For instance, the government has two main instruments to maintain mountain landscapes and biodiversity: the contribution to alpine pasture[15] and the contribution to summering.[16] The former amounts to CHF 370 per "pâquier-normal" (PN) per year. A "pâquier-normal" is a standard pasture unit. It is equivalent to one head of a Livestock Unit (LU) grazing on roughage for 100 days in mountain areas (Alps, Voralps or Jura). Switzerland comprises 300,000 PN grazing on 465,000 ha and concerns 7000 livestock owners. The contribution to summering was raised in 2014 in order to incite farmers to maintain the grazing activity and prevent forest invasion. It currently amounts to CHF 400/PN and CHF 500/PN for sheep with herd protection. Both measures are intended to prevent forest encroachment on open landscapes and to preserve biodiversity (OFAG, 2023).

Despite such instruments, forest encroachment on pasturelands continues. According to Brändli et al. (2020), the forest area in Switzerland expanded by 130,322 ha between the first forest inventory (1983–1985) and the last (2009–2017), which corresponds to a 11% growth rate. The largest share of the forest expansion is found in Alpine areas, at the expense of pastures.

Other policy instruments are the Biodiversity Promotion Areas (BPA) which aim to conserve biodiversity in meadows by controlling mowing dates and use of fertilisers. Farmers are compensated by direct payments for the induced yield losses. BPA showed their effectiveness in conserving biodiversity (Ravetto Enri et al., 2020). **Thus, grazing by cattle is one of the most efficient measures to promote biodiversity on a large scale**.

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[15] Alpungsbeitrag/Contribution de mise à l'alpage.
[16] Sömmerungsbeitrag/contribution à l'estivage.

However, promoting grazing on natural pastures will not suffice to conserve or restore biodiversity.
The crucial point related to grazing on natural pastures is the stocking density and the most challenging point is its management throughout the growing season and across the years. Too high and too low stocking densities will both result in biodiversity losses, by allowing certain plants to overrun others. In Switzerland, stocking densities and length of pasture are ruled by cantons which fix the number of PN per summer pasture farm. The stocking density can be adapted according to meteorological events, for example. Both overstocking and understocking, will end in a diminishing, and ultimately suppression of, financial contribution (OFAG, 2023).

It must be noted that livestock grazing for 100 days in summer depend on fodder and feed grown over summer in other areas, to be sustained for the remaining 265 days and three seasons of the year (spring, autumn and winter). This fodder can originate from summer pastures (hay), but to a larger extent originates from temporary meadows in croplands destined for silage and/or hay, as well as grown fodder (maize for silage, temporary mixed crops in the rotation, etc.). Much of the fodder destined for livestock and cropped in the lowlands plays a crucial role in the standard crop rotation and should not be forbidden, because, ultimately, it is destined to feed livestock.

The current “feed no food” discourse, which aims to decouple cropping activities in the lowlands and livestock grazing in mountain areas, ignores the crucial role of temporary feed crops in crop rotation. It also ignores soil health and its crucial role in sustaining summering livestock in the lean season.

The management of natural grazing grounds is a common practice in many countries, especially those with a long tradition of pastoralism, such as countries in Central and Southern Europe, the Caucasus, sub-Saharan Africa, the Middle East, Central Asia, the Andes and the Himalaya. Over centuries, traditional grazing management rules were overrun by either disruptive conflicts or rules imposed by newly formed States that were considered more “modern”. In most cases, this resulted in a disruption of local management systems and led to the so-called “*Tragedy of the Commons*” theorised by Hardin (1968). In countries like Kyrgyzstan, Tajikistan, or Mongolia, attempts to overcome the tragedy of the commons were undertaken by establishing pasture user committees (PUC) or pasture user groups (PUG). Unfortunately, the low respect for rules by pasture users and low enforcement by PUC leaders often led to failures in addressing the problem.

Overpopulation of livestock is often seen as the main cause of the tragedy of the commons and a reduction in their numbers as a straightforward way to tackle the problem. This simplistic approach again ignores the complexity of pastoralist systems. Social, governance, economic, and political issues, as well as family and personal trajectories, intricately influence pastoralism practices, including the number of livestock and stocking density.

4.8 Land-sparing vs land-sharing debate

In the past decade, a lively debate around the notion of “land sparing” and “land sharing” emerged (Balmford et al., 2012; Adams, 2012; Tscharntke et al., 2012). Land sparing aims to conserve biodiversity in specific areas by strictly keeping out any human interventions. This approach, thereby almost by default, leads to an intensification of other areas used for food production.

This approach emerged from the tropics where large tracts of "pristine" habitats (e.g. tropical forests) are being converted to crop and pastureland. Land sharing is another approach to landscape management, in which biodiversity conservation and agricultural production occur on the same land. This is the case in Europe, where agricultural production is traditionally multifunctional. Herzog and Schüepp (2013) highlighted the fact that the land-sparing vs land-sharing debate is too reductive for the European context, where marginal areas are subject to rural abandonment and productive land is being intensified. Instead, the two authors recommend to differentiate between productive farmland, where biodiversity conservation measures are promoted, and marginal farmland, where semi-natural habitats were traditionally managed by farmers and yield high-value products such as meat and milk.

Organic farming is one form of land sharing. However a study done on 1470 fields across 205 organic and conventional farms in 12 areas in Europe and Africa showed that, at farm level, biodiversity (expressed in bird, insect, worms and spiders) was not significantly different between organic and non-organic farms (Schneider et al., 2014). Species richness was statistically different at field level, with a higher diversity on organic farms, especially for birds and insects. The production of food, however, was lower on most organic farms compared to their paired "conventional" farm. This shows that the traditional way of farming in Europe, which includes semi-natural habitats, allows a combination of agricultural production and conservation of biodiversity in habitats shaped by human activities, including livestock rearing.

The study's authors concluded that in order to combine food production and biodiversity goals in Europe, it is more important to conserve existing semi-natural habitats for biodiversity than to separate plots for biodiversity conservation and plots for agricultural production as promoted by proponents of the land-sparing approach. This is even more important because many species living in semi-natural habitats probably have a high ecological valence and may disappear if kept away from croplands. The authors concluded that exclusive biodiversity reserves are needed for very sensitive species.

In a nutshell: the role of livestock in food systems transformation

- *Livestock contributes various products and services to humankind and impacts humans in four main domains: food and nutrition security, economy and culture, health and welfare, and environment.*
- *Food systems evolved over millennials and centuries, as political, economic, societal, technological, legal, and environmental factors changed.*
- *Livestock-derived food has been a component in varying degrees: first to hominin's diets and later to human species' diets.*
- *The consumption of LDF is price sensitive (high income elasticity), which affects the intake level.*
- *The consumption, or not, of LDF is ingrained in religion and/or culture and therefore more resistant to change.*
- *Livestock provides essential services to crop production in the form of draught power and manure. The value of this indirect contribution to food security exceeds the value of direct contribution through products (meat, milk, etc.).*
- *Livestock produces other goods and services for energy production (biogas), ecosystems (biodiversity, soil health, carbon storage), culture, tourism, etc.*
- *Contrary to products, services rendered by livestock are often not monetised and their value overlooked.*
- *Ignoring the value of livestock services in the narrative around GHG emissions will trigger unwanted knock-on effects on the whole food system.*

- *Pastures, first grazed by wild herbivores and later also by domestic herbivores, dominated the world's ecosystems for millennials and represent a huge carbon stock.*
- *Pasture management plays an important role in promoting the positive effects of animal husbandry for ecosystems and livelihoods.*
- *Livestock is at the heart of the feed/food competition and land-sharing and land-sparing debates.*

5. Possible pathways to food system transformations: case studies

Summary of this chapter:
This chapter highlights selected avenues to make livestock's contribution to the food system more sustainable. The general call for a reduction in the livestock population in the Global North must be in line with a reduction in the consumption of LDF, otherwise the environmental footprint will only be relocated to other areas where environmental and animal protection policies are less stringent. The main risk associated with a call for reducing the number of livestock is the fact that marginal areas might be the first ones to reduce their stock, mainly for economic and social reasons. The return of large predators is likely to play a non-negligible role in this trend, especially for sheep.

The reduction or abandonment of livestock in these areas with a high environmental value can result in rural abandonment. This trend is observable in all of Europe.

Global diet of livestock is actually composed of 86% feed and fodder inedible to humans, such as grass and leaves, stubbles, and stalks. The remaining 14% are grains and other edibles. Crop residues, oil seed cakes and by-products represent one third of the diet inedible to humans. This can be further strengthend through a consequent re-adoption of circular approaches recentering livestock production based on their natural feed (roughage to ruminants, residues to monogastrics).

There is currently a strong move towards true cost accounting (TCA) of products and services. In the case of livestock, costs related to environmental pollution (e.g. GHG emissions) would be expressed as net costs, which means, for example, that CO_2 sequestration in grasslands and water infiltration should be counted. Currently, this is not the case as asssessing CO_2 sequestration in soils requires more complex life cycle assessment (LCA) methods than the ones currently used.

In most countries, actors in human and animal health operate "in silos" under different institutional entities (ministries, health institutions, state and private operators). The One Health approach seeks to enhance collaboration across the three sectors and between its respective stakeholders through improved interactions between humans, animals and ecosystems health.

Solutions to render livestock production more sustainable cannot be proposed by ignoring (intentionally or not) the systemic dimension of livestock systems and the role they play in the agricultural system, the wider food system, and the overall ecosystem. Due to the intrinsically complex nature of the food system, solutions will be complex and will entail inevitable trade-offs (FAO, 2023). FAO (2023) identified four key triggers for the transformation of food systems to achieve four "betters" in the food system: better production, better nutrition, better environment, better life:

- Improved governance
- Increased consumer awareness
- Better income and wealth distribution
- Widespread technological, social and institutional innovations.

The four FAO triggers are in line with the four key factors used in the theory of change model from previous CNS-FAO publications (CNS-FAO, 2016) to identify and discuss possible pathways for transformation (Fig. 9).

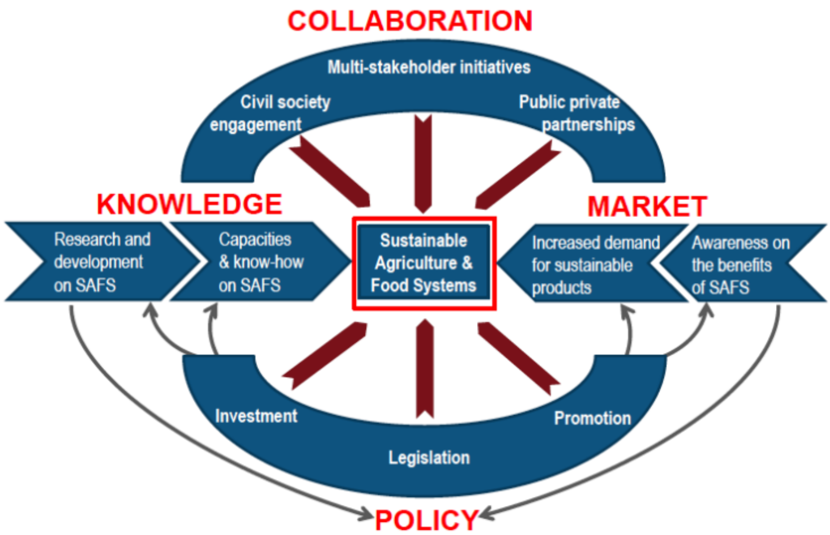

Figure 9. Theory of change: Four key factors (in red) need to work together to achieve a change towards sustainable agriculture and food systems (CNS-FAO, 2016).

FAO's key drivers	CNS-FAO's theory of change
• Improved governance	▪ Collaboration, Policy
• Increased consumer awareness	▪ Market
• Better income and wealth distribution	▪ Market
• Widespread technological, social and institutional innovations	▪ Knowledge (research, capacities)

The following subchapters show examples of systemic approaches and measures currently undertaken worldwide and in Switzerland to tackle specific aspects of livestock production.

5.1 Circular economy

The world has 5 billion ha of agricultural land, which corresponds to 38% of the global land surface. These 5 billion ha comprise 3.5 billion ha of permanent grasslands. The claim that livestock uses a large proportion of agricultural land is therefore correct. It is, however, not correct to claim that all areas devoted to livestock could be converted to arable land. The 3.5 billion ha of grasslands encompass 1.5 billion ha of grasslands in marginal areas, not used by livestock and not convertible to croplands. Of the total grassland area currently used by livestock (2 billion ha), 684.9 million ha could be converted to cropland. This corresponds to 14% of the total agricultural land and 5% of global arable land (Mottet et al., 2017). However, converting grasslands would incur biodiversity loss and increased CO_2 emissions in its wake.

The figures related to land use, though correct, provide a reductive picture of livestock in the "feed/food" debate; namely, they neither show the role played by livestock to recycle crop residues, and crop by-products and co-products, nor the importance of temporary meadows in the crop rotation for soil health and control of crop diseases and pests. Mottet et al. (2017) showed that the global diet of livestock is actually composed of 86% feed and fodder inedible to humans, such as grass, leaves, stubbles, and stalks. The remaining 14% are grains and other edibles. Crop residues, oil seed cakes and by-products represented one third of the diet inedible to humans.

In Switzerland, permanent grasslands make up 58% of the agricultural land[17], while arable land and permanent crops make up 38% and 2%, respectively, of the total agricultural land (BLW, 2022). Approximately 60% of arable land is used to produce feed and fodder for livestock (e.g. maize, temporary meadows).

One objective of Switzerland's climate strategy on agriculture and food systems by 2050 is "*to optimise production portfolios*" by devoting arable land primarily to food production for humans. Livestock shall be fed on grasslands outside arable land and with by-products from agricultural commodities processing (BLW, BLV, BAFU, 2023).

Stettler and Probst (2023) estimated the number of livestock necessary to use such grassland and by-products in Switzerland. They showed that reducing[18] feed production on arable land in Switzerland to have a more optimal use of these areas would provoke the following changes: poultry, suckler cows and calves for veal production would disappear, the number of pigs would be reduced to one third of the current herd, while the number of dairy cows, their milk and meat production, sheep and goats would be maintained at current levels. Such a scenario would mean that consumers ether drastically change their current diet or that poultry meat, eggs, pork, beef and veal are imported from abroad.

Besides grass, ruminants and monogastrics have a great potential to upgrade to high-value products (meat, eggs, milk, manure), residues which would in the worst case be burnt, discarded in waterways or left to rot. Of course, such products can also be composted or digested to produce energy (pyrolysis, biogas). This is increasingly done (see next chapter on energy).

Nevertheless, a balance must be found between food security, soil health and nutrition, crop rotation, control of disease, and pest pressure on crops. Van Zanten et al. (2019) showed that returning livestock back to their natural feed (roughage to ruminants, residues to monogastrics) would allow to simultaneously feed humans with high-value products and keep practices within planetary boundaries. To achieve this, the approach to livestock production needs to move away from a linear approach and adopt (again) a circular approach (Fig. 10).

[17] Surface agricole utile (SAU), Landwirtschaftliche Nutzfläche.
[18] Eliminating feed production, but keeping 20% of temporary meadows in the crop rotation.

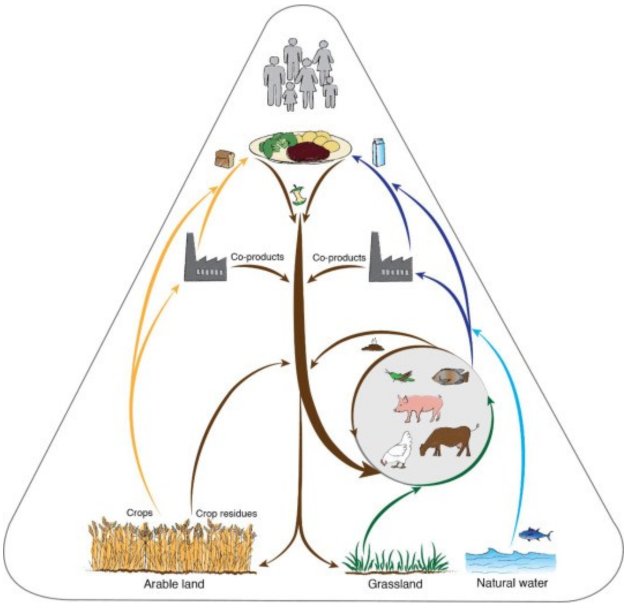

Figure 10. Biophysical concept of circularity (Van Zanten et al., 2019)

Adopting a circular approach at policy level requires various preconditions:

- A thorough understanding of agricultural systems with livestock subsystems as a component.
- A thorough understanding of the food system with all value chain stakeholders, steps in the value chain and market demand.
- A political will to have all actors sitting at the same table to move forward. Strengthening policy coherence would allow the regulatory framework to develop and better leverage the potential of circular approaches.
- A transdisciplinary approach to tackle issues and find solutions .

5.2 Holistic systems approach

It was previously demonstrated that livestock is a part of agricultural systems and the wider food systems worldwide. The integration of livestock in the cropping system enhances the system's overall productivity and resilience; therefore, providing a way towards sustainable intensification, particularly under climate change (Peterson et al., 2020). Promoting integrated (or circular) systems is seen as a promising avenue to tackle climate change, soil fertility depletion and biodiversity loss, while ensuring food security.

In Europe, integrated crop–livestock systems resembling what we now call agroforestry systems date back to the Middle Ages. EURAF (2022) defines agroforestry as "*the integration of woody vegetation, crops and/or livestock on the same area of land. Trees can be inside parcels or on the boundaries (hedges).*"

Agroforestry comprises the following subsystems:

- Trees & Crops: agrisilvicultural or silvoarable systems
- Trees & Livestock: silvopastoral systems (SPS)
- Trees, crops & livestock: agrosilvopastoral systems

According to Missouri University, a silvopastoral agroforestry practice focuses on combining trees, forage and livestock and is a planned and intentional system. Agroforestry is viewed as one promising avenue for the transformation of the current food system worldwide (Gasner and Dobie, 2022).

Old forms of agroforestry in Europe evolved in a societal system revolving around three classes and their dwellings: the peasants (villages), the priests (churches) and the lords (castles). The agrosilvopastoral system was centred around the village in a circular form:

1st circle: crops
2nd circle: orchards
3rd circle: communal grazing grounds (*les Communs/Allmend*)
4th circle: forest for wood, non-timber forest products (NTFP), leaves as feed and litter for livestock

This system was used for centuries until World War II, when it was abandoned in the productivism period that followed.

In Switzerland, the most famous silvopastoral systems were the traditional orchards (*Hochstämme/hautes tiges*) in the country's east, the forest pastures (*Waldweide/pâturages boisés*) in the Jura, and the chestnut groves in Ticino and Valais. These systems were abandoned or neglected due to different policies; for example, farmers were forced to remove apple orchards in eastern Switzerland under a policy to combat alcoholism and fruit oversupply. Between 1950 and 1970, 1 million trees were felled (srf1). Hedges were burnt and uprooted to provide space for tractors and sunlight to crops.

Recently, agroforestry has been promoted in Switzerland and the European Union (EU) again; this time, centering on its environmental value and contribution to ecosystems. Currently in Switzerland, 8% of the agricultural land is used for agroforestry (both agropastoral and agroarable systems). The promotion of agroforestry is done through IG Agroforst, established in 2011 in the Swiss-German region. In the French-speaking part, agroforestry is promoted by the Plateforme agroforesterie romande. Both associations comprise 130 members. The government supports agroforestry through **direct payment** for biodiversity promotion and landscape quality, but not for wood used as energy.

The European Agroforestry Federation (EURAF) was established in 2011 and represents 24 countries and 500 members. The area under agroforestry (mostly silvopastoral form) in the EU comprises 15 million ha (=9% of the utilised agricultural area); 52 million ha if reindeer production is included. The EU Common Agricultural Policy (CAP) listed agroforestry as an Ecological Focus Area for ecological payments in pillar I (Reg. (EU) No. 1307/2013). In its Green Deal (dated 11 December 2019) and "Farm to Fork" Strategy (20 May 2020) to reduce net GHG emissions by at least 55% by 2030, compared to 1990 levels, the EU included organic production, agroecology, agroforestry, and precision farming as main avenues.

Europe is not the only region with traditional agroforestry practices – Southeast Asia, Africa and Latin America have them, too. Watson (2019) documented some of these systems, such as the Sawah Tambak rice-fish system in Indonesia, Kihamba forest gardens in Tanzania, the Milpa and its Three Sisters (beans, maize and squash) component in the Maya tradition in Meso America, and Kayapo Apete Forest Islands in Brazil. Another example of an integrated system is the Vuon (garden), Ao (pond), and Chuong (pigsty) (VAC) system in Vietnam.

Some countries "rediscover", "reinvent", adapt or perfect old forms of integrated systems. Several Latin American countries currently research and implement various forms of integrated systems: integrated crop-livestock-forestry (ICLF) systems, intensive ones with eucalyptus, high-yielding crops (cotton, soja, maize) and grass (*Brachiaria spp*. g) and Nellore cattle and traditional systems with native tree species, natural grass and Criollo cattle (Calle et al., 2013).

5.3 Integrated landscape systems

Other examples of integrated management go beyond the integration of crops, trees and livestock with emphasis on the natural and economic dimensions of sustainability. Some examples also strengthen the social (and hence cultural) dimension of sustainability, such as landscape management in The Burren on the western Atlantic coast of Ireland. Abandonment of grazing in this area, for economic reasons, is threatening the more than 6000-year-old man- and livestock-made landscape and its rich biodiversity.
The EU-funded Burren Life Project was piloted with 20 farms to revive pastoralism in the area (Flintan et al., 2022). Key interventions included: payment for ecosystem services, celebrating local culture, providing advice at local level, and incentives and alternatives to more intensive forms of farming (e.g. silage making instead of grazing). The approach is now being expanded to 100 farms with the hope that cultural heritage will be preserved and water resources and biodiversity improved.
Livestock is used in landscape restorative practices (UNCCD, n.d.). In dry and abandoned areas in southern Europe and in the Alps, small ruminants, especially goats, are used to browse in the forests to maintain biodiversity and prevent forest fires. Highland cattle are also used for this purpose in Ticino and in the Vosges (Bourgeois, personal observations). In Switzerland, the animal breeding policy for 2030 foresees the following main axes of intervention (OFAG, 2018):

- Food production meeting market requirements
- Preservation of animal genetic resources
- **Vitality in rural areas**

5.4 Differentiated adjustment of livestock populations

Driven by the increasing demand resulting from increasing population, improved purchasing power and changing consumption habits, the world's livestock population continuously increased over the past 60 years (FAOSTAT, 2023) and is expected to do so for at least the next 20 years (OECD and FAO, 2022). Poultry exhibited the largest population increase, with a factor of 8.5 (Table 1).

	Heads in 1961	**Heads in 2020**	**Increase factor**
	940 million	1.5 billion	1.6
	994 million	1.3 billion	1.3
	349 million	1.2 billion	3.4
	406 million	953 million	2.3
	3.9 billion	33 billion	8.5
	88 million	204 million	2.3

Table 1. Source: FAOSTAT, accessed 1 January 2023.

Production increase followed the increased demand for LDF, especially in LMIC mentioned earlier. Currently, the largest livestock populations are mostly found in LMIC. Asia has the largest poultry, goat, sheep and pig herds. The Americas have the largest cattle herds, mainly thanks to/because of Latin American countries. Table 2 shows where the largest herds for the six main livestock species are located.

	Largest herds	**2nd largest herds**
	Brazil (beef)	India (193 million, dairy and draught)
	India (112 million)	Pakistan (42 million)
	China (5.2 billion)	Indonesia (3.5 billion)
	China (455 million)	USA (75 million)
	China (186 million)	India (74 million)
	India (149 million)	China (133 million)

Table 2. Source: FAOSTAT, accessed 1 January 2023.

In the EU, the livestock population (expressed in livestock units) is dominated by cattle, followed by pigs, poultry, sheep, and goats; however, it is unevenly distributed across countries, thereby reflecting not only major differences in agroecological zones, food consumption habits and cultural heritage, but also in specialisation favoured by policies. Almost half (45%) of the cattle are kept in three countries: France, Germany and the UK. Spain and Germany alone account for 38.4% of the EU's pig population. The UK and Spain account for 45% of the sheep population, while Greece and Spain account for half of the EU goat population (CWGSAP, 2019). The average stocking density at EU level is 0.8 Livestock Unit (LU) per ha of utilised agricultural area (UAA). Livestock densities vary tremendously across individual member states, with Bulgaria exhibiting the lowest densities (0.2 LU/ha UAA) and the Netherlands the highest (3.8 LU/ha UAA). These figures show that reductions in livestock numbers need to be differentiated at country level. Two countries in the EU are currently hotly debating the need to reduce livestock numbers: Ireland and the Netherlands.

In 2021, Switzerland was home to 48,864 farms, of which 71% were livestock farms (the majority cattle farms), 20% were crop farms and 9% were mixed farms. Between 1999 and 2021, the number of farms in Switzerland diminished from 73,591 to 48,864: a loss of 24,727 farms (-33.6%). The loss was higher for livestock farms (-35.3%) than crop farms (-30.4%) or mixed farms (-26.1%). Farms in hilly or mountain regions hold proportionally more livestock than farms in the lowlands (OFS, 2022).

The total number of livestock decreased by 4% in the past 20 years (OFAG, 17 November 2020); however, the decrease does not affect all categories. Between 1985 and 2021, the highest decrease was observed with pigs (-30.5%) and cattle (-18.1%). Other categories all registered increases (+114% for horses, +28% for sheep, +53% for goats and +100% for poultry) (OFS, 2022). Poultry is steadily increasing to meet the increasing demand for poultry products (eggs and meat) (BLW, 2022).

The general call for a reduction in the livestock population in Switzerland must be in line with a reduction in the consumption of LDF, otherwise the environmental footprint will only be relocated abroad where environmental and animal protection policies are less stringent. It must be reiterated that already more than 50% of the environmental footprint of Switzerland's food system originates abroad. To achieve this, rather than advocating for vegan or vegetarian diets, advocating for the flexitarian diet (with less LDF) would probably be better accepted by the wider population.

The main risk associated with a call for reducing the number of livestock is the fact that marginal areas might be the first ones to reduce their stock, mainly for economic and social reasons. The return of large predators is likely to play a non-negligible role in this trend, especially for sheep. The reduction or abandonment of livestock in these areas with a high environmental value can result in rural abandonment. This trend is observable in all of Europe and has been extensively described by Herzon et al. (2022) in boreal regions as the "*socio-ecological extinction vortex*". In other regions of the world, reduction or elimination of livestock under rewilding schemes will result in its replacement by wild herbivores, comprising both ruminants and hindgut fermenters, with the likelihood that GHG emissions remain stable. Manzano et al. (2023) showed that wild herbivores grazing and browsing in the protected Serengeti area in Tanzania emit comparable or even greater amounts of GHGs than domestic herbivores kept in the Loliondo Game Controlled Area, an adjacent and comparable ecozone.

Ways to address the social, economic, and environmental issues mentioned above need to be tailored to each region. Financial incentives through direct payments to farmers are unlikely to be sufficient to overcome the issue of the rural abandonment or rewilding schemes. Keeping a vibrant tourism industry, good infrastructure, reliable public transport, adequate schooling, shopping, and lodging opportunities will also be key to keep such areas alive.

5.5 True costs

There is currently a strong move towards true cost accounting (TCA) of products and services. True costs are the total production costs of a product, entailing not only economic costs, but also social and environmental ones. A range of TCA methods exist, with different ways of accounting that complicate comparisons (de Adelhart Toorop et al., 2021). In parallel the discourse on taxing polluting products gains momentum. Policy measures ensure that true costs are expressed as net costs. In the case of livestock, costs related to environmental pollution (GHG emissions) are expressed as net costs, which means, for instance, that CO_2 sequestration in grasslands and water infiltration will be accounted. This is not the case at present, because considering CO_2 sequestration in soils requires more complex life cycle assessment (LCA) methods than the ones currently used. This leads to an unjustified negative bias towards livestock products and positive bias towards vegetal-based products.

5.6 One Health approach: institutional concept

One Health is a concept describing interactions between human, animal and ecosystem health, and ways to address them. The concept has been institutionalised by the World Organisation for Animal Health (WOAH), previously known as Office International des Epizooties (OIE).
In most countries, actors in human and animal health operate "in silos" under different institutional entities (ministries, health institutions, state and private operators). The One Health approach seeks to enhance collaboration across the three sectors and between its respective stakeholders.

Although the One Health approach is still poorly adopted worldwide, a number of successes can already be attributed to this collaborative, holistic, multi- and transdisciplinary approach. One example is highlighted below.

Fight against antimicrobial resistance (AMR)
Resistance of microorganisms (bacterial, viral, parasitic and fungal) to antimicrobial medicine is not only a major public health threat, it also jeopardises food security and sustainable development (WOAH, 2022). It is estimated that AMR caused 4 million deaths in 2019, of which 1.3 million were directly imputable to resistant bacteria (Murray et al., 2022). The wrong or abusive use of antimicrobials in human and animal health, including aquaculture, is a major cause of AMR. Agriculture is not spared: recent research published by CABI showed that antibiotics are often erroneously prescribed to treat viral or fungal diseases (Taylor and Reeder, 2020). It is estimated that 10% of rice produced in Asia is treated with antibiotics. Although the bulk of antibiotics are used in human and animal medicine, resistances are estimated to develop faster when antibiotics are used in crop production. Increased movements of animals, humans and goods through globalisation also contribute to the spread of resistant microorganisms. The WOAH's Global Action Plan on Antimicrobial Resistance began in 2010 to urge countries to develop and implement national plans to fight AMR.

In Switzerland, the sales of antibiotics in livestock production has continuously decreased in past years: between 2013 and 2022 by 52% (BLV, 2023). The use of antibiotics considered critical for human health decreased at an even faster pace (7% per year). In 2015, Switzerland developed the "Strategy to Antibioresistance (StAR)". Switzerland also set up the Swiss Centre for Antibiotic Resistance (ANRESIS) to monitor antibiotic consumption and resistance. Monitoring of antibiotic resistance in zoonotic indicator bacteria was established in 2014, in line with EU guidelines. This allows Switzerland to monitor resistance in cattle, pigs and poultry and compare its results with those from EU countries and Norway.

The Livestock Antimicrobial Partnership (LAMP) is an action network within the Global Agenda for Sustainable Livestock and hosted by the Swedish University of Agricultural Sciences (SLU). SLU compiled and published a set of good practices for responsible use of antibiotics in several regions of the world and for different livestock species (poultry, dairy cattle).

6. Conclusions and recommendations

The food system must be transformed to become more resilient, more sustainable, and more inclusive, to respect Earth's boundaries and preserve ecosystems. Simultaneously, food systems must improve their efficiency to ensure and improve food security in all regions of the globe. This implies fundamental mind shifts and measures leading to societal transformation. All food system actors – producers, processors, citizens, consumers, policymakers, researchers, etc. – must change their behaviour and attitudes to include long-term perspectives, differentiated views and a systemic approach.

As a crucial component of food systems, the wider society and ecosystems, the livestock sector must be an integral part of the transformation path along with other systems components such as agriculture, transformation and food logistics. The livestock sector remains essential to support the livelihoods, health and nutrition of people and the ecosystem in a more inclusive, resilient, and sustainable way.

The challenge in the transformation process is to move away from current blueprint and simplistic approaches, and to tackle inevitable trade-offs, such as: *GHG reduction <=> water efficiency, feed/food competition <=> ecosystems services, manure <=> fossil fertiliser, soil fertility <=> energy, linear economy <=> circular economy.*

This report to the Swiss Government and interested stakeholders proposes a set of recommendations structured along the theory of change models used in this research (Fig. 9) and differentiated at global and national levels for each of the five following thematic fields:

- Building an inclusive and resilient food system as a whole
- Livestock, natural resources, nutrient cycles, biodiversity and climate
- Livestock, food and nutrition security, and health
- Livestock production and economics
- Livestock, regional development and cultural heritage.

The recommendations are structured along four key factors, all pivotal for sustainable transformation of food systems (CNS-FAO, 2016): **Knowledge, Market, Collaboration** and **Policy** (see point 5). These four factors define priorities of possible implementation, identify actors and underline the importance of a coordinated and holistic approach.

To support a systemic understanding of the food system – its trade-offs and interdependencies, knowledge generation and translation into action – requires research and development activities of public and private entities. These activities need to focus on how to make production systems and supply chains more sustainable and applicable within the given context.

Market demand is a decisive pull factor. Raising consumer awareness on health, social, economic and environmental issues is crucial. Predictable and fair market mechanisms, based on clear and transparent regulatory frameworks which aim to strengthen agency and participation of all food system actors, are an important prerequisite and require coordinated measures of public and private entities.

Collaboration between different stakeholders to jointly tackle issues or advance promising approaches stand a better chance of success. No single actor can accomplish the transformation of sustainable food systems and the advancements needed towards the 17 SDGs on its own.

Different multistakeholder platforms, initiatives and networks exist globally to jointly drive food system transformations. The recommendations derived from these platforms need to be adopted and incorporated into global recommendations, national policies, industry standards and strategies as well as research and educational programmes.

A conducive policy environment is the essential fuel for the transformation of food systems and the livestock sector in order to achieve scale. Supportive governance structures across sectorial silos and efficient decision-making processes are a key ingredient to support food system actors to move ahead in an integrated and evidence-based manner, including all relevant stakeholders.

6.1 Building an inclusive and resilient food system as a whole

Global level	
Policy	▪ Promote political stability and the rule of law and to fight corruption. ▪ Promote gender equality, inclusion, and equal rights. ▪ Promote access to long-term land(use) rights serving as incentives for farmers to invest in long-term sustainable production practices and thereby preventing overexploitation of natural resources. ▪ Establish science-based voluntary guidelines at multilateral level supporting policymakers in dealing with the complexity of livestock systems. ▪ Promote and roll out policies on sustainable and healthy diets.[19] ▪ Provide youth with cultural, social, economic, financial, technological, and legal incentives to take an active role in agriculture, livestock and the food system. ▪ Strengthen policy coherence allowing regulatory frameworks to develop to best leverage the potential of circular approaches. ▪ Identify and communicate inevitable trade-offs based on evidence. ▪ Capitalise on outcomes of the UN Food System Summit +2 (Rome, Italy, July 2023) in a constructive, inclusive and pragmatic way.
National level in addition to global measures	
Policy	▪ Map food systems at national level. ▪ Identify and communicate inevitable trade-offs based on national specificities and scientific evidence. ▪ Strengthen the application of "nutrient budgets" at farm and aggregated levels. ▪ Shift policy on all levels of the food chain towards sustainability outcomes and empower all stakeholders to take responsibility by implementing measures, practices and technologies best adapted to local agroclimatic conditions, e.g., supporting programmes using a landscape approach. ▪ Enable the private sector to define and adopt industry-wide sustainability standards.
Example(s) of possible measures for Switzerland	
	▪ Swiss stakeholders from the food system play an active role at FAO and other international multistakeholder platforms in their strategic work supporting the transformation of global food systems.

[19] https://journals.sagepub.com/doi/full/10.1177/0379572120976253

	▪ Stimulate the creation of a national food system strategy that builds on scientific evidence and economic realities and promotes decentralised and sustainable local production and sustainable and healthy diets through an increased policy coherence across different policy domains. ▪ Establish private-sector-driven networks, like those existing on palm oil and soy, to define and increase sustainability standards on feedstuff, which self-declare those standards as mandatory for the whole sector.

6.2 Livestock, natural resources, nutrient cycles, biodiversity and climate

Global level	
Policy	▪ Urge FAO (and other institutions) to supervise and monitor the consequences of regional sustainability initiatives on the flow of feed/animal products and by-products, for example by linking to the Agricultural Market Information System (AMIS). ▪ Enable access to long-term land(use) rights serving as incentives for farmers to invest in long-term sustainable production of livestock. ▪ Promote improved practices and technologies leading to efficiency gains and aiming to minimise the negative impact of the livestock sector on environment (through, e.g., incentives for ecosystem service provision through extensive/integrated grazing/rangeland management systems). ▪ Support the production of ruminants on grassland, favour grassland in areas with agroclimatic conditions which do not (under regular conditions) require irrigation, while disincentivising the production of feed on land resources which could be used for food production. ▪ Advocate for land-sharing rather than land-sparing. ▪ Limit CO_2 emissions through trading of certificates at the international level. The current international CO_2 certification is not efficient to decrease CO_2 emissions and should be replaced or improved. ▪ Define industry guidelines banning trade of agricultural products such as crops, feed and livestock products which were produced on deforested surfaces. ▪ Foster and harmonise measuring tools on farms to allow comparison and more research on practices and implementation.
Knowledge	▪ Support the development of concepts and models supporting circular agriculture at landscape level – inspired by traditional methods and knowledge, combined with scientific insights and novel solutions – aiming to minimise the use of external inputs, water and land as well as the negative impact on biodiversity. ▪ Accelerate research and development to create new processes that reduce GHG emissions at all stages of the livestock production process. ▪ Make a clear differentiation in the "CO_2 emission budget" between emissions of fossil origin and other emissions. ▪ Develop teaching materials and peer-to-peer learning formats and awareness-raising campaigns to inform producers and consumers

	about the potential to increase resource efficiency in livestock production e.g., through circular approaches which aim to reduce waste, a consumption of animal products beyond recommended quantities and nutrient surplus and improving soil health.
Markets	▪ Improve access to public or private capital to enable investment in circular approaches in livestock production. ▪ Maximise the use of by- and side-products occurring in food systems for feed of all animal categories. ▪ Increase the efficiency of (especially blue) water use in the production of feed and food (all food, not only animal-source food) by introducing water-saving practices and techniques. ▪ Promote measures supporting the reduction of meat consumption in countries where the consumption level of animal-based protein exceeds the scientifically recommended level. ▪ Adopt practices and technological solutions reducing GHG emissions in production and across the entire food system.
Collaboration	▪ Promote multistakeholder initiatives for sustainability initiatives at international levels. ▪ Intensify the exchange of good practices across existing networks (GASL, ATF, CWG-SAP).
National level in addition to global measures	
Policy	▪ Develop strategies/initiatives considering country-specific aspects (in a process involving all relevant actors of the food system) which aim to reduce livestock's negative impact on climate and ecosystem services, meanwhile supporting the positive impact on farmers' livelihoods and ecosystem services through e.g., supporting programmes using a landscape approach. ▪ Support the production of ruminants on rainfed grassland while disincentivising the production of feed on land resources which could be used for food production. ▪ Strengthen incentives that compensate ecosystem services using landscape approaches. ▪ Implement and extend policies to foster transparency on negative livestock systems which do not respect national environmental laws, to enable consumers to make a conscious decision while shopping. ▪ Advance true cost accounting along the whole food chain. ▪ Optimise circular nutrient and energy cycles in livestock production systems through policies, extension, and education. ▪ Replace incentives which generate negative externalities like inefficient high energy and nutrient inflows, needlessly long supply chains and loss and waste in food and feed systems. ▪ Define policy-based measures supporting the reduction of meat consumption in countries where the consumption level of animal-based protein exceeds the scientifically recommended level. ▪ Develop a reward system for carbon sequestration and eco-system services on farm and landscape levels. ▪ Incentivise investments in decentralised energy production based on available resources (wood, biogas, pyrolysis, photovoltaic, heat

	recovery, etc.) while not harming croplands, forests, food production, landscapes and biodiversity.
Knowledge	▪ Accelerate research on pragmatic carbon measuring methods and tools and ecosystem service compensation models. ▪ Better translate research in adoptable and scalable practical tools adjusted to local context.
Markets	▪ Invest in and facilitate short, safe and circular nutrient cycles using a landscape approach as well as within and between rural and urban areas. ▪ Develop private standards and labels to positively indicate good practices in livestock production systems. ▪ Increase energy efficiency and accelerate the production and use of sustainable energy on farms (solar panels on buildings, biogas, reutilisation of heat etc.).
Collaboration	▪ Get inspired by good practices developed and promoted through multistakeholder initiatives (e.g., GASL) and apply them within local context. ▪ Facilitate collaboration between livestock holders, investors (public and private) and researchers to develop circular and low-energy systems.
Example(s) of possible measures for Switzerland	
	• Improve and share practices and technologies leading to efficiency gains and aim to minimise the negative impact of the livestock sector on environment with relevant food system actors from other countries and the FAO. • Support context- and climate-adapted production of ruminants. • Take measures for a more healthy and sustainable diet by motivating the population to consume meat more consciously and to reduce the amount of animal protein to the recommended level according to the food pyramid, while considering the “nose to tail” principle.

6.3 Livestock, food and nutrition security, and health

Global level	
Policy	▪ Develop global policies which improve livelihoods of ruminant farmers on extensive grasslands in order to keep this important food production potential in the system. ▪ Develop global awareness-raising campaigns which aim to improve overall health of diets and bring average consumption of animal-based proteins to a level which meets dietary recommendations, while reducing the environmental impact. ▪ Shape inclusive and climate-sensitive food and livestock systems. ▪ Advance the One Health approach and strengthen policy coherence to support its implementation.
Knowledge	▪ Better highlight key principles of sustainable livestock production (including all sustainability dimensions) by providing a holistic understanding about the contribution of livestock systems to the food system in general. ▪ Improve consumers' awareness of One Health, globally.

Market	▪ Improve access to capital markets to enable investment in circular, integrated and resilient livestock production, and improve practices and technologies leading to nutrition and nutrient efficiency gains across regions. ▪ Ensure year-round access and affordability to sustainable and healthy diets.
Collaboration	▪ Facilitate and promote short supply chains and exchange between producers and consumers leading to more agency and diversified food systems.
National level in addition to global measures	
Policy	▪ Stimulate the creation of a national food system policy that promotes local production and sustainable and healthy diets[20] through an increased policy coherence across different policy domains. ▪ Develop science-based, awareness-raising campaigns (codeveloped and implemented by a variety of food system actors) to illustrate the role of livestock in food systems. ▪ Research and respond with locally adapted measures to new trends in food consumption, nutrition and energy efficiency. ▪ Advance the One Health approach.
Knowledge	▪ Produce, in collaboration with actors from across the food system, modern educational materials (e.g. videos or social media kits) promoting sustainable and healthy diets and the multifunctional role of livestock for nutrition and ecosystems. ▪ Develop modern education materials on sustainable and healthy diets and One Health to improve awareness and knowledge through school feeding programmes, campaigning in canteens, on social and mass media, and via farmers hubs.
Market	▪ Ensure year-round access and affordability to sustainable and healthy diets. ▪ Minimise food loss and waste along the whole supply chain as well as in consumption. ▪ Advertise sustainable and healthy food (warn against ultra processed foods, whether vegetal or livestock based). ▪ Provide attractive producer prices and affordable choices (e.g., at canteens, restaurants, etc.) to consumers and customers.
Collaboration	▪ Develop "sustainable livestock platforms" (e.g. mini-GASLs) at national level to raise awareness of livestock's role in sustainable diets using a One Health approach. This platform should involve all relevant actors across the food system to identify priorities, measurable goals and concrete actions. ▪ Link food system actors to develop local or regional food systems, with locally produced, environmentally friendly, affordable, and nutritious food.
Example(s) of possible measures for Switzerland	
	▪ Promote GASL as the knowledge and advocacy platform to advance sustainable livestock for food systems transformation.

[20] https://journals.sagepub.com/doi/full/10.1177/0379572120976253

	▪ Initiate at FAO level a set of voluntary guidelines on how to improve livelihoods of ruminant farming families on extensive grasslands in order to sustainably use their food-production potential long term. ▪ Promote the food pyramid from the Société suisse de nutrition (SSN) in schools, restaurants etc. ▪ Develop "sustainable livestock platforms" (e.g. mini-GASLs) at national level to raise awareness of livestock's role in sustainable diets using a One Health approach. This platform should involve all relevant actors across the food system to identify priorities, measurable goals and concrete actions, and hence stimulate national food system policy.

6.4 Livestock production and economics

Global level	
Policy	▪ Better integrate least-developed countries (LDCs) and their processed and raw products into global markets. ▪ Advocate for policies and support mechanisms that promote resilient livestock farming, long-term sustainable systems and locally adapted farming systems that consider the resources' limits. ▪ Reduce trade barriers and promote investments into agroecological livestock systems and biodiverse landscapes.
Knowledge	▪ Promote research for climate-resilient integrated agriculture and livestock production systems which serve food agencies and contribute to global food security. ▪ Invest in conflict-sensitive resource governance where pastoralist and farming communities interact.
Market	▪ Fully integrate women into markets by ensuring stable and equitable access to assets, means of production and markets.
Collaboration	▪ Support processes at multilateral level (including representatives from various sectors) to develop science-based methodologies for true cost and true value accounting of food (and livestock) systems.
National level in addition to global measures	
Policy	▪ Support processes at national level (including representatives from various sectors) to develop science-based methodologies for true cost and true value accounting of food (and livestock) systems as well as of other products from the agricultural sector.
Knowledge	▪ Secure access to professional education and maintain attractiveness and excellence in food production and processing based on environmental and social safeguards.
Market	▪ Maintain and enhance infrastructure, excellence and jobs in food processing. ▪ Maintain and strengthen agency over the access of affordable food and healthy and balanced diets for all.
Collaboration	▪ Set up platforms to reach agreement on the processes involved in changing the food system and encourage initiatives to develop voluntary industry-wide standards.
Example(s) of possible measures for Switzerland	

	▪ Foster policies that improve market integration of LDC by facilitating trade stability and minimise trade barriers within the framework of the FAO and relevant international treaties. ▪ Ensure that the current supply of educational programmes (vocational training and advanced programmes) promote healthy and sustainable diets and remain attractive and qualitatively excellent

6.5 Livestock, regional development and cultural heritage

Global level	
Policy	▪ Highlight the role of animals in the foundation of societies throughout the world (e.g., through 'patrimoine culturel immatériel de l'humanité'). ▪ Create incentives to protect the genetic biodiversity of animal species and breeds, and marginalised ecosystems which benefit from low intensive grazing schemes (mountains, marshlands, etc.), to protect from bushfires and to maintain biodiversity. ▪ Prevent rural exodus by supporting sustainable forms of livestock production. ▪ Safeguard cultural heritage and ceremonies related to livestock in harmony with modern lifestyles.
Knowledge	▪ Raise awareness about the importance of livestock in the socioeconomic, environmental, and cultural development of "marginal areas" and promote the role of animals in the foundation of societies throughout the world. ▪ Offer distance education and easy-access educational materials for livestock farmers and pastoralist families. ▪ Include food and diet history into basic and advanced education curricula.
Market	▪ Promote local and authentic livestock products which strengthen local and decentralised economies. ▪ Explore and promote synergies between livestock production systems and tourism (camel, yak or alpaca trekking, etc.). ▪ Strengthen and explore ethical business models to market traditional livestock-based practices and ceremonies for new clients. ▪ Explore and research new ways (e.g., better adapted to climate change) of keeping livestock.
Collaboration	▪ Explore through multistakeholder platforms synergies between cultural value of livestock and modern lifestyles (e.g., tourism).
National level	
Policy	▪ Continue intensifying the promotion of circular economies and decentralised renewable energy and nutrition cycles – short supply chains. ▪ Stimulate local economic development (e.g., agrotourism). ▪ Make a clearer, explicit link between culture, products, breed preservation and ecosystem services within a given local context.
Knowledge	▪ Develop educational materials on large predators (wolf, lynx, bear) and the impact on livestock ecosystems, biodiversity, and tourism. ▪ Develop interactive games to rebuild understanding of agriculture and livestock ecosystems.

Market	▪ Better link products and ecosystem services (e.g., in existing labels) and better promote them (e.g., dairy products in extensive alpine regions). See link to true cost and true value of food. ▪ Attract investment in local initiatives to adapt traditional livestock keeping to modern lifestyles (e.g., tourism). ▪ Explore new business models to market ecosystem services (e.g., measures to prevent wildfires, biodiversity conservation, etc.). ▪ Develop storytelling around sustainable production forms, products, and producers.
Collaboration	▪ Link food systems actors and beyond to develop local or regional food systems. ▪ Explore innovative ways to rebuild trust and mutual respect between rural and urban food systems actors. ▪ Explore ideas how (agri-)culture bridges gaps between rural and urban populations (e.g., link with tourism).
Example(s) of possible measures for Switzerland	
	▪ Food branding: Promote cultural, environmental, socioeconomic values linked to animal products, breed preservation and ecosystem services: some examples are rather successful (e.g., the role of the Eringer cow in culture, cheese and beef production and grazing of alpine meadows, Schwarznasenschaf in Wallis, Franche Montagne horse in Jura, etc. The Concours des médailles in Canton of Jura or le Salon des Goûts et Terroirs in Bulle could be a platform to make these links more explicit. ▪ Link actors to develop local or regional food systems, with locally produced, environmentally friendly, affordable and nutritious food, e.g., “*Bärn isst bio*” or other local food networks.

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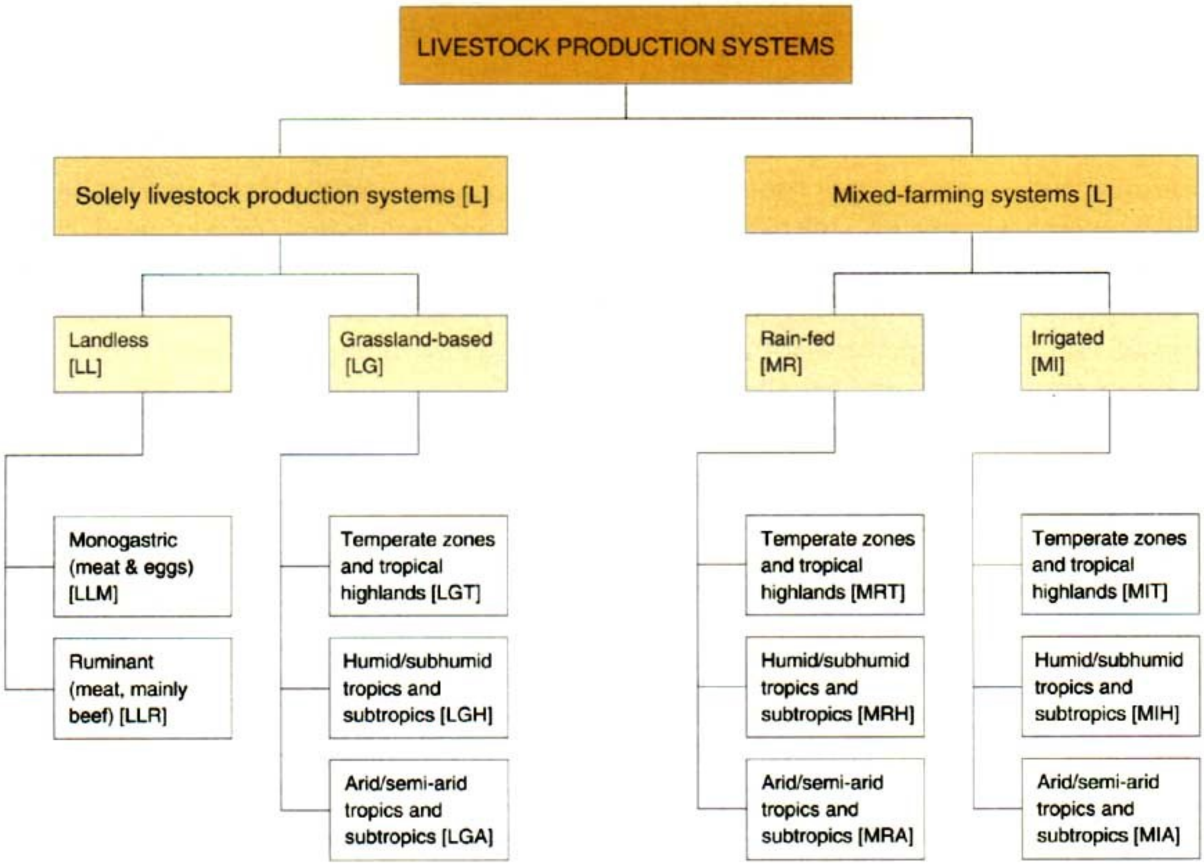
Annex 1 Classification of livestock systems (Seré and Steinfeld, 1996)



Source: Steinfeld H. and J. Mäki-Hokkonen.
https://www.fao.org/3/v8180t/v8180T0y.htm#conclusions

Annex 2 Mandate for the publication

- Scope: National und international
- Fokus: Transformationsaspekt – Welche Funktionen/ Rollen soll die Tierhaltung in der Transformation hin zu klimasensiblen und nachhaltigen Ernährungssystemen wahrnehmen?
- Aufbauen auf bestehenden Wissen: Das Papier soll auf bestehendem Wissen des Beitrags von der Tierhaltung zur Transformation der Ernährungssysteme und unter Berücksichtigung des Klimawandels aufbauen. Differenzierte Perspektive (räumlich, kulturell) => Achtung Binaritäten!
- Abbildungen und Ansätze helfen: Das Papier soll die systemische Perspektive abbilden. Entsprechend könnten die Inhalte gemäss Abbildung Transformation: Shifting the conditions that hold systems in place (Moser et al., 2019: Transformation from science to decision-making; Abbildung auf Seite 2) und dem OECD-Ansatz https://www.oecd.org/publications/making-better-policies-for-food-systems-ddfba4de-en.htm