LIVESTOCK'S LENGTHENING SHADOW

A 20-YEAR RETROSPECTIVE ON THE FAO'S LANDMARK ASSESSMENT OF LIVESTOCK AND THE ENVIRONMENT

June 2026

STOP FINANCING FACTORY FARMING

ACKNOWLEDGEMENTS

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The **Stop Financing Factory Farming** Campaign works in partnership with locally affected communities and organizations to shift development finance away from industrial livestock production towards healthier, more humane and sustainable food systems. The campaign's global Steering Committee includes: Compassion in World Farming, Friends of the Earth U.S., International Accountability Project, Sinergia Animal, and World Animal Protection. The campaign has more than 30 organizational members and partners globally.

COVER PHOTOS: Slavcho Malezan/Lucas van Oort - UNSPLASH
REPORT DESIGN BY: Marie Melvin

TABLE OF CONTENTS

‘Agro-industrial systems, consisting of input-intensive monocultures and industrial-scale feedlots currently dominate farming landscapes. The uniformity at the heart of these systems and their reliance on chemical fertilizers, pesticides and preventive use of antibiotics, systematically yields negative outcomes and vulnerabilities. ... The environmental impacts, including water, soil and air pollution, of intensive livestock production are significant.’

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. This is an intergovernmental body with over 120 member countries.

OVERVIEW

In 2006 the UN Food and Agriculture Organisation (FAO) published Livestock's Long Shadow, the first detailed analysis by a major international body of the detrimental impact of the rearing of farmed animals on the environment. The report stressed that 'the livestock sector emerges as one of the top two or three most significant contributors to the most serious environmental problems, at every scale from local to global' and 'Livestock's impact on the environment is already huge, and it is growing'.

Now, twenty years on, it may be helpful to assess to what extent the role of farmed animals as a driver of environmental problems has been addressed and whether further measures are needed to tackle this. In doing so, we need to look at both the harmful impacts of industrial animal farms themselves and the problems that arise from the production of feed – particularly grain and soy – for the animals. We must also examine the detrimental outcomes of the expansion of pastures for ruminants.

Comparing the position as described in Livestock's Long Shadow with the present situation can be challenging as, in some cases, there are no current metrics that are equivalent to those used in the 2006 study. For example, greenhouse gas emission figures are not directly comparable due to changes in methodology and system boundaries while deforestation data use varying geographic definitions making like-for-like comparisons unreliable. Nonetheless, the position that emerges when comparing the present day with the world of Livestock's Long Shadow is that in many environmental fields, livestock's shadow has lengthened — that is, the environmental damage caused by animal production has grown in scale and severity since 2006, driven in large part by a 53% increase in the annual number of mammals and poultry farmed worldwide (see Table 1).

This huge increase in the annual number of animals farmed over the last twenty years has resulted in two destructive developments - expansion and intensification:

Expansion - The increasing demand for land:

- to grow soy and cereals to feed the rising number of industrially farmed animals, and
- as pasture for cattle

leads to expansion of farmland into forests, savannahs and other key ecosystems with massive loss of wildlife habitats and biodiversity as well as release of stored carbon into the atmosphere.

Intensification - The need for feed by industrial animal production has fuelled the intensification of crop production. This, with its use of monocultures and synthetic fertilisers and chemical pesticides, has led to overuse and pollution of ground- and surface-water,[1] soil degradation,[2] [3] biodiversity loss,[4] and air pollution.[5] In short, industrial animal agriculture undermines the key resources on which long-term productive farming depends.


Sows confined in stalls so narrow that they cannot even turn round. They suffer from stress, frustration and hunger © Shutterstock

In some cases, efficiencies may have reduced a particular environmental impact per unit of animal-source food produced, but the huge increase in the number of animals farmed has resulted in an increase in the overall magnitude of that environmental impact. This is, for example, the case with climate change.

Livestock's Long Shadow report considers several environmental factors separately such as biodiversity loss, climate change and land degradation. However, in reality the impact of farmed animals on differing environmental elements is closely intertwined; one driver may concurrently impact several environmental factors. For example, much of the nitrogen in fertilisers used to grow grain and soy as animal feed is not taken up by the crops. Similarly, much of the nitrogen in the compound feed given to intensively farmed animals is excreted in animal manure.

This unabsorbed nitrogen:

- Pollutes rivers, lakes, wetlands and marine ecosystems
- Contributes to air pollution through the formation of particulate matter which can lead to respiratory problems
- Erodes biodiversity, for example by acidifying soils
- Contributes to climate change by producing nitrous oxide.

Haiyue Jing et al (2025) describe how agricultural intensification (much of which has arisen to provide feed crops for intensively farmed animals) has led to habitat loss, agrochemical pollution, water depletion, and soil degradation.[6]

The authors state: 'Our findings show that despite increased agricultural yields, intensification has led to severe habitat fragmentation, reduced genetic diversity, and disrupted ecological connectivity. The widespread use of agrochemicals negatively affects pollinators, natural enemies, non-target species, and soil fauna. Excessive irrigation contributes to eutrophication, altered river flow patterns, depletes groundwater reserves, and shrinks wetlands. Meanwhile, soil degradation exacerbates biodiversity loss by damaging soil structure, accelerating erosion, reducing fertility, and increasing salinization.'

Huge increase in the number of mammals and poultry farmed

Despite Livestock's Long Shadow's warning of the detrimental impact of animal production on the environment and human health, the number of animals that are farmed annually has risen by 53% since publication of the report; see Table 1 which sets out FAO data.[7]

Table 1: The number of mammals and poultry slaughtered and farmed for milk & eggs in 2006 and 2023

Note: In some cases the figures in Table 1 relate to animals farmed and slaughtered in the year in question, e.g. in the case of most poultry and pigs as these animals are mainly slaughtered when less than one year of age. In other cases the below figures relate to animals farmed but not slaughtered in the year in question, e.g. dairy cows and laying hens are normally over one year of age when slaughtered.

ANIMALS	2006	2023
Buffaloes	22,076,100	28,519,240
Cattle	303,689,116	309,870,057
Chickens	48,333,204,000	76,245,629,000
Goats	376,158,025	543,794,638
Pigs	1,223,343,654	1,511,950,905
Sheep	520,245,890	695,482,414
Ducks	2,262,504,000	4,188,010,000
Dairy cows (used for milk: not necessarily slaughtered that year)	243,020,294	292,041,780
Hens (used to produce eggs)	5,917,333,000	8,441,860,000
Total terrestrial animals slaughtered/used [there are more species included in this total than just the selected species above]	61,806,864,976	94,944,831,002

Source: FAOSTAT, 2025. Database 'Crops and livestock products'. Figures for 2023. https://www.fao.org/faostat/en/#data/QCL

In 2023 the UN Environment Programme said that over the last decade global production of meat, milk and eggs increased by about 15%, 18% and 22% respectively.[8]

The Stop Financing Factory Farming coalition is opposed to industrial animal production including industrial pig and poultry and beef feedlot production.

We also oppose large-scale extensive cattle production as much of this is carried out on land that has entailed deforestation or the destruction of other key ecosystems.

We support smallholder farming of animals to high animal welfare standards. Farmed animals can be an integral part of nature-friendly practices including agroecology, integrated crop-livestock systems, agroforestry, organic farming and silvopastoral systems. Good grassland systems for raising cattle and sheep do not feed grain to the animals and minimise the use of chemical fertilisers. The pasture includes legumes such as clover which can minimise the use of both nitrogen fertilisers and soy as they are rich in protein.

Planetary Boundaries

The scale of the failure to curb the environmental impact of animal farming becomes even clearer when viewed through the lens of the Planetary Boundaries framework, which has emerged since 2006 as a key tool for assessing the limits within which humanity can safely operate. Research has established nine Planetary Boundaries which, if crossed, could generate irreversible environmental changes and drive the planet into a much less hospitable state.[9]

The Planetary Boundaries concept establishes three zones. When humanity functions within the Planetary Boundaries we are in a Safe Operating Space. Once a particular boundary is crossed, we move into a Zone of Increasing Risk. In this zone, the further the boundary is exceeded, the greater the chance of causing serious damage and destabilizing key Earth system processes. Once this zone is exceeded, we enter a High Risk Zone where there is a strong possibility of severe, irreversible damage to key planetary functions that support life.

The 2025 Planetary Health Check concludes that seven out of the nine Planetary Boundaries – Climate Change, Change in Biosphere Integrity, Land System Change, Freshwater Change, Modification of Biogeochemical Flows, Introduction of Novel Entities, and Ocean Acidification have been breached.[10] All of those seven show trends of increasing pressure – suggesting further deterioration and destabilization of planetary health in the near future.[11] The production of farmed animals is among the key drivers of these breaches of the Planetary Boundaries.

DETAILED EXAMINATION OF KEY ENVIRONMENTAL FACTORS ADVERSELY IMPACTED BY ANIMAL FARMING

1. Greenhouse gas emissions

KEY MESSAGES

1. Livestock's Long Shadow calculated that farmed animals were responsible for around 7.1 billion tonnes of CO2eq per year. Recent studies indicate that livestock emissions have risen to 8.5-9.8 billion tonnes of CO2eq per year. The FAO states that emissions from farmed animals grew by 22% between 2001 and 2023.

2. Animals are responsible for over 50% of the greenhouse gas (GHG) emissions from food production.

3. The industry claims that emissions can be reduced by measures such as technical solutions and improving animals' productivity. However, while the emissions intensity (amount of emissions per unit of food) of animal products has fallen since 2006, the absolute amount of GHG emissions produced by farmed animals has risen since the publication of Livestock's Long Shadow.

4. The World Bank's report *Recipe for a Liveable Planet* states: 'Emissions from agrifood must be cut to net zero by 2050' and stresses that 'demand-side measures to curb meat demand are much more cost-effective than ... supply-side measures.'

5. Climate scientists state that global emissions from the animal sector should drop rapidly, by 50% by 2030, and 61% by 2036 and that the most effective options for reducing emissions are through reduced production of animal-source food.

6. te Wierik et al. (2025) have established food system boundaries that aim to ensure that food systems play their part in helping the world to return to safe operating spaces.[1] For climate change they propose a food system boundary of 5 Gigatonnes (Gt) CO2eq per year whereas food systems currently produce around 16.5 Gt CO2eq per year.

Livestock's Long Shadow estimated that farmed animals are responsible for 18% of total anthropogenic greenhouse gas (GHG) emissions.

Since then this figure has been much disputed and discussed. In a 2014 report the FAO revised this figure, calculating that farmed animals produce 14.5% of global GHG emissions.[12] More recently, a 2021 paper suggests the figure is higher at 16.5%.[13]

Then in 2023 the FAO re-calculated and reported that farmed animals are responsible for approximately 12% of all anthropogenic GHG emissions.[14] Also in 2023 the UN Environment Programme calculated that animal products – including animal emissions, feed, changes in land use and energy-intensive global supply chains – account for a total of 14.5–20% of global emissions.[15]

The differing percentages produced by studies arise in part from methodological differences making it difficult to compare animals'carbon footprint as calculated by the above studies. Moreover, the key issue is arguably not the percentage of total global GHG emissions produced by farmed animals, but rather whether their total emissions are rising or falling. Here too finding clear figures is not straightforward, again due to methodological differences.

Livestock's Long Shadow calculated that animals were responsible for around 4.6 billion tonnes of CO2eq per year; that figure rises to approximately 7.1 billion tonnes of CO2eq per year when emissions from the land use, land-use change and forestry category are included.

FAO data show that in 2023 global agrifood systems emissions reached 16.5 billion tonnes of CO2eq, up 21% since 2001.[16] Our World in Data calculates that farmed animals are responsible for 52% of the GHG emissions from food production; 30% emanate from animal and fish farms, 6% from the production of crops for animal feed, and 16% from land use for animals.[17] On the basis of these FAO and Our World in Data figures, farmed animals are responsible for 8.58 billion tonnes of CO2eq per year, a clear increase from the figure in Livestock's Long Shadow.

Xu et al (2021) calculated that global emissions from the production of food were 17.3 billion tonnes of CO2eq per year and that animal-based foods are responsible for 57% of food-related emissions.[18] On the basis of Xu et al's figures, farmed animals are responsible for 9.8 billion tonnes of CO2eq per year, also a clear increase from the figure in Livestock's Long Shadow. The FAO stated in 2023 that, compared with 2001, 'livestock emissions grew by 22%'.[19]

The industry claims that emissions can be reduced by measures such as technical solutions and improving animals'productivity. However, while the emissions intensity (amount of emissions per unit of food) of animal-source products has fallen since 2006,[20] the absolute amount of GHG emissions produced by animals has risen since the publication of Livestock's Long Shadow (see previous two paragraphs).

It would be extremely damaging to allow emissions from farmed animals to continue to rise. The World Bank's report *Recipe for a Liveable Planet* states: 'Emissions from agrifood must be cut to net zero by 2050' and stresses that 'demand-side measures to curb meat demand are much more cost-effective than … supply-side measures.[21] Studies show that further major growth in animal farming is incompatible with the World Bank target.[22]

To avoid catastrophic levels of climate change, global production of meat and milk must be greatly reduced. © AegeanBlue via Getty Images

Harwatt ***et al***. (2024) surveyed over 200 climate scientists and sustainable food/ agriculture experts.[23] The survey indicates:

- there are no credible pathways to meeting the Paris Agreement that allow GHG emissions from animal farming to continue growing;
- global emissions from animal farming should peak by 2025 and then drop rapidly, by 50% by 2030, and 61% by 2036 and that the most effective options for reducing emissions are through reduced production of animal-source products.

te Wierik et al. (2025) have established food system boundaries that aim to ensure that food systems play their part in helping the world to return to safe operating spaces.[24] For climate change this study proposes a food system boundary of 5 Gt CO2eq per year whereas, as indicated above, food systems currently produce around 16.5 Gt CO2eq per year.

2. Biodiversity loss and ecosystem degradation

KEY MESSAGES

1. The farming of animals is perhaps the single largest driver of biodiversity loss and reduced ecosystem services.
2. We need to consider not just natural biodiversity and special ecosystems but also farmland biodiversity. Achieving good crop yields largely depends upon the conservation of agrobiodiversity including soil biodiversity.
3. We must avoid harmful spillovers from farmlands to the wider environment such as the large volumes of nitrogen and phosphorus discharged from the manure of industrially reared pigs and poultry and feedlot cattle.
4. The expansion of cattle pastures and the intensive production of soy as feed for industrially farmed animals are key drivers of tropical deforestation.

Livestock's Long Shadow states: 'the livestock sector may well be the leading player in the reduction of biodiversity, since it is the major driver of deforestation, as well as one of the leading drivers of land degradation, pollution [and] climate change'.

This assessment was repeated in 2017 by the UN Convention to Combat Desertification which said that 'When the amount of land used for grazing and feed crops is combined, livestock production accounts for around 70 per cent of agricultural land and is perhaps the single largest driver of biodiversity loss and reduced ecosystem services'.[25]

Land use, land-use change, pollution and climate change associated with industrial animal agriculture systems are important drivers of biodiversity loss. Intensively raised animals have a detrimental impact on biodiversity and ecosystems in many different ways. These include:

- Expansion of land to grow feed crops or for grazing into forests and other ecosystems can result in loss, degradation and fragmentation of habitat which can lead to wildlife declines and even extinction of species.
- Agricultural intensification to produce animal feed crops. This, with its use of monocultures and agro-chemicals, can lead to degraded habitats with minimal diversity in plants and animals and lacking nesting sites, shelter and

Organic composted soil with worms © Shutterstock

feed for farmland birds and beneficial insects. It can also decimate farmland soil biodiversity thereby eroding the fertility that is essential to achieving good crop yields.

- Pesticides are often used in the production of grain and soy as feed. The FAO points out that pesticides show 'a broad range of lethal and sublethal effects on insect pollinators, and in particular on bees'.[26] They also kill beneficial insects that act as natural enemies of pests.[27] Pesticide runoff from farms can also have serious impacts on fish and amphibians, which can cause reduced survival rates and population declines.[28,29]

- Animal production is a major contributor to climate change which has many negative impacts on biodiversity. Increasing temperatures and altered rainfall patterns can result in changes in the vegetation and wildlife that are able to grow and live within certain areas forcing plants, animals and disease-causing insects to migrate to new areas.

- The use of nitrogen and phosphorus fertilisers to grow cereals and soy for animal feed leads to the pollution of rivers, lakes and marine ecosystems resulting in the death of fish and other aquatic organisms and, at the worst, creating huge 'dead zones'.

The 2025 Planetary Health Check reports, regarding Biosphere Integrity: 'Both the loss in genetic diversity as well as in the functional integrity of the biosphere have exceeded their safe levels' suggesting further deterioration in the near future.[30] Crucially, it stresses: 'Nature's safety net is unraveling: Extinctions and loss of natural productivity are far above safe levels, and there is no sign of improvement'.

The Planetary Health Check identifies agriculture as a key driver of loss of biosphere integrity. It states that other drivers include land system change, climate change, freshwater change, and modification of biogeochemical flows – as is shown elsewhere in this report, all these are adversely affected by industrial animal farming including the production of feed.

The 2025 Planetary Health Check found that the extinction rate remains above 100 extinctions per million species years (E/MSY) far beyond the Planetary Boundary of 10 E/MSY. Moreover, human appropriation of net primary production (HANPP) sits at 30% – triple the 10% Planetary Boundary and above the 20% high-risk level. This situation has persisted or slightly worsened since 2024, with ongoing loss of genetic diversity and ecosystem function.

Need to consider not just natural biodiversity but also farmland biodiversity

For some years the 'land-sparing' argument has over-simplified and clouded discussions on how to restore biodiversity. Some argue that by farming land intensively, other land can be spared from

In 2026 the UK Government published a new National Security Assessment entitled *Global Biodiversity Loss, Ecosystem Collapse and National Security*. To the best of our knowledge this is the first time a Government has said that global biodiversity loss and ecosystem degradation are a threat not just to food security, but to national security.

The Assessment states: 'The world is already experiencing impacts [of ecosystem degradation] including crop failures, intensified natural disasters and infectious disease outbreaks … Cascading risks of ecosystem degradation are likely to include geopolitical instability, economic insecurity, conflict, migration and increased inter-state competition for resources.'

It warns: 'If current rates of biodiversity loss continue, every critical ecosystem is on a pathway to collapse'. The Assessment states: 'Food production is the most significant cause of terrestrial biodiversity loss.'

agriculture and remain in, or be restored to, a biodiversity-rich state.

This is an unrealistic static approach which overlooks the dynamic, regularly evolving nature of ecosystems. It ignores the fact that if agricultural land is farmed intensively with the use of monocultures and agro-chemicals it will over time degrade, leading to reduced yields and the need for fresh land to be brought into agriculture. The UN Food and Agriculture Organization has warned that undue emphasis on high productivity can lead to declining soil quality with the result that 'food production is seriously affected, the result being a vicious downward spiral'.[31] In short, overworking farmland in the erroneous belief that this can preserve natural biodiversity is a shortsighted strategy.

We need instead to protect and restore both agricultural and natural biodiversity. Garcia-Vega et al (2024) point out that 'agricultural biodiversity contributes to nurturing soils, pollinating crops, reducing pests' pressures, and increasing the overall performance of crops. Maintaining the productive capacity of agroecosystems, in the long run largely depends upon the conservation of agrobiodiversity'.[32]

Avoiding harmful spillovers from farmlands to the wider environment

We must avoid harmful spillovers from farmlands to the wider environment. For example, the large volumes of nitrogen and phosphorus in the manure of industrially reared pigs and poultry can run off into waterways and erode biodiversity in rivers and other watercourses.

Moreover, ammonia is formed when faeces and urine interact in intensive farms and when deposited in high concentrations, it can acidify soils by over supplying nitrogen. Plant species adapted to high nutrient availability thrive in the nitrogen-rich environment created by ammonia and out-compete species which are more sensitive, smaller or rarer.[33]

Excess nitrogen has negative effects on sensitive habitats such as peatlands, heathlands and bogs – it enables nitrogen-tolerant plants to outperform lichens and mosses that have lower nitrogen requirements. Moreover, when it reacts with other gases, ammonia can form fine particulate matter which can result in serious respiratory diseases, cardiovascular issues, lung cancer, and premature death.

Deforestation for feed and pastures

Large-scale industrial animal production also has detrimental impacts on natural biodiversity through its demand for soy and grain as feed for pigs, poultry and feedlot cattle as well as grassland for large-scale extensive cattle.

Livestock's Long Shadow highlighted the problem of the expansion of pasture and animal feed crops into natural ecosystems, saying that 'the destruction of natural habitats to establish agricultural land use means direct and significant biodiversity losses'.


Industrial feed production is causing steep declines in pollinators. © Shutterstock

It reported that 'animal production is certainly one of the driving forces of deforestation'.

This problem continues today and can most vividly be seen in the impact of animal production on deforestation. Forests harbour most of Earth's terrestrial biodiversity.[34] Every year, the world loses around four million hectares of forest; 95% of this occurs in the tropics.[35,36]

Agriculture – such as clearing forests to provide pasture for cattle and grow crops including soy for animal feed – accounts for 70–80% of tropical deforestation.[37]

The below studies highlight that the clearing of forests for cattle ranching and soy production are key drivers of tropical deforestation. In the period 2018–2022 the expansion of cattle pasture in the Amazon region averaged 1.3 million hectares per year.[38] Deforestation and conversion in Brazil linked to soy production amounted to 794,000 hectares in 2022.[39]

Song et al (2021) calculated annual soybean expansion in South America between 2000 and 2019 by combining satellite observations and sample field data.[40] From 2000 to 2019, the area cultivated with soybean more than doubled from 26.4million hectares to 55.1million hectares.

Most soybean expansion occurred on pastures originally converted from natural vegetation for cattle production. The most rapid expansion occurred in the Brazilian Amazon, where soybean area increased more than tenfold between 2000 and 2019, from 0.4 million hectares to 4.6 million hectares.

Our World in Data shows that 41% of tropical deforestation is driven by pasture expansion for beef, while 18.4% is driven by cropland expansion for oilseeds – this is dominated by soy and palm oil.[41] 76% of global soy production is used as animal feed.[42] Of the soy used as feed, three-quarters is fed to pigs and poultry which worldwide are the most industrial animal farming sectors, while less than 3% is fed to cattle which in much of the world are raised extensively on grass.[43]

The Cerrado

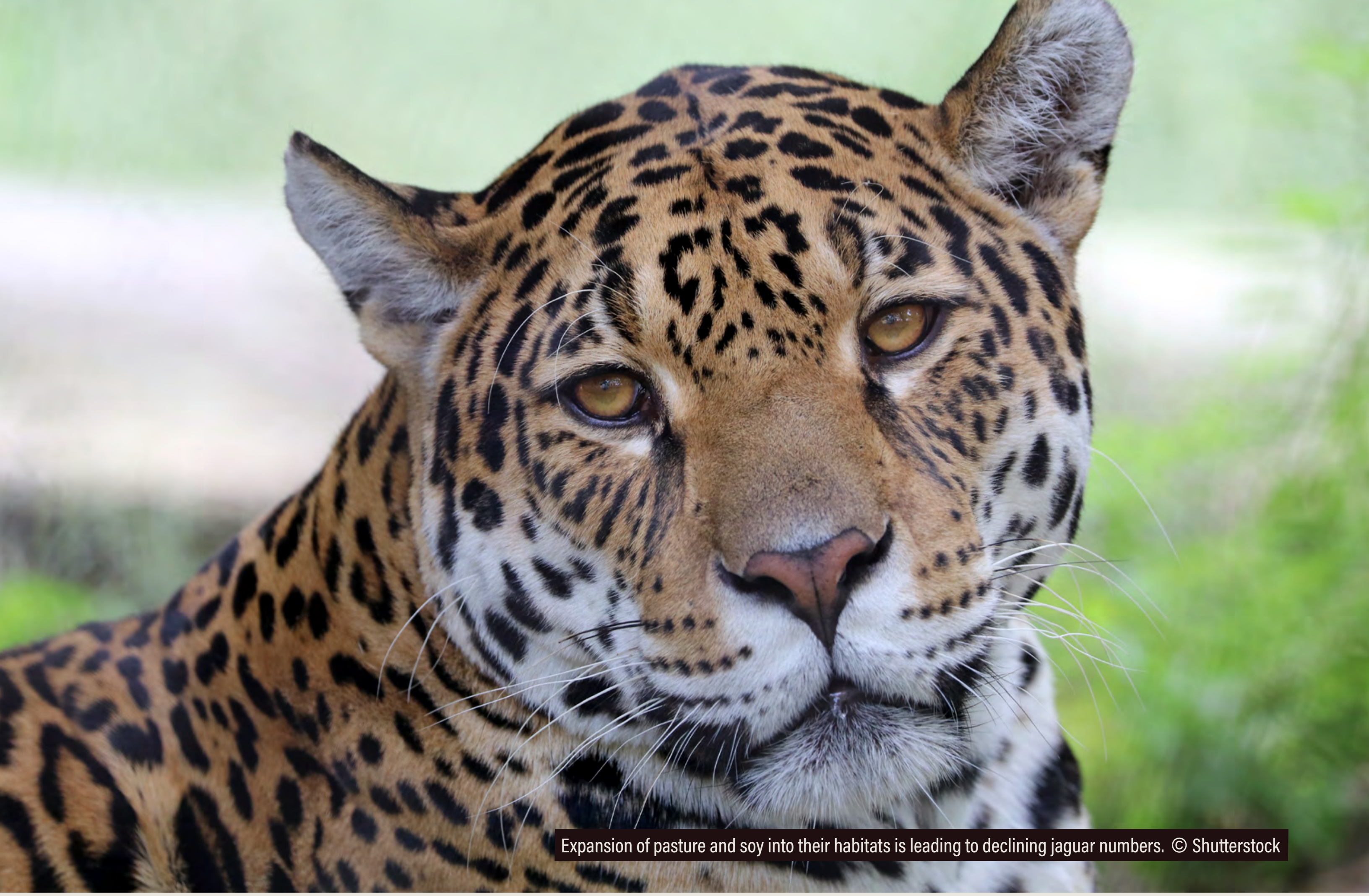
Livestock's Long Shadow reported that in the Cerrado 'mammals such as the giant anteater, giant armadillo, jaguar and maned wolf still survive. Biodiversity in this fragile and valuable ecosystem is endangered by a combination of fragmentation, intensification, invasions and pollution'.

The report added: 'over the past 35 years, more than half of the Cerrado's original expanse of two million km² has been taken for agriculture. It is now among the world's top regions for the production of beef and soy'.

Since the publication of Livestock's Long Shadow the Cerrado has continued to lose native vegetation to cattle pastures as well as soy and grain. The World Economic Forum states that over the past 20 years the Cerrado has lost 30 million hectares of its native vegetation by being converted to agriculture, for example for soy and corn production both of which are often used as animal feed.[1] In 2025 Agência Brasil, a news agency run by the Brazilian government, reported that the human activities in the Cerrado were primarily pasture and agriculture, which by 2024 accounted for 24.1% and 13.2% of the biome's territory, respectively. [2]

[1] World Economic Forum, 2024. The Cerrado: Production and Protection. https://www3.weforum.org/docs/WEF_Sustainable_Transition_Cerrado_2024.pdf

[2] Agência Brasil, 2025. Brazilian Cerrado biome lost 28% of native vegetation in 40 years. https://agenciabrasil.ebc.com.br/en/meio-ambiente/noticia/2025-10/brazilian-cerrado-biome-lost-28-its-native-vegetation-40-years


Expansion of pasture and soy into their habitats is leading to declining jaguar numbers. © Shutterstock

Erosion of genetic diversity of farmed animals

Livestock's Long Shadow stressed that more than 6,300 breeds of domesticated livestock have been identified but that this livestock genetic diversity is threatened. The report stated that in 2000 over 1,300 of the breeds were extinct or considered to be in danger of extinction.

Today just a few breeds dominate commercial chicken and pig production. Just two companies produce the two main hybrid breeds used in most of the world's industrial broiler chicken farms.[44] Also, two dominant companies produce the breeds used in many of the world's egg-laying flocks.[45] Similarly, just a handful of companies provide the breeding stock for most of the world's commercial pork production.[46]

This erosion of genetic diversity carries high risks. The low genetic variability in commercial poultry flocks has contributed to the spread of avian influenza as well as to the ability of low pathogenic avian influenza to evolve into highly pathogenic avian influenza.[47] [48] A key study in this area says: 'The fact that entire flocks in commercial operations are decimated during avian flu outbreaks could be a reflection of low genetic variability in … immune response genes'.[49] Moreover, high genetic uniformity may lead to decreased resilience to climate change as well as to pests and diseases.[50]

3. Land use and land use change

KEY MESSAGES

1. Animals use 80% of global farming land but only produce 18% of the world's calories and 37% of total protein.
2. The annual global use of grain as animal feed has increased by 63% between 2002 and 2025.
3. There has been a 27% increase in the amount of global cropland used to produce animal feed since the publication of Livestock's Long Shadow.
4. 'No matter how efficiently animal-based food is produced, using arable land to produce feed for its production will always be less efficient than using it directly as food': *Appetite for change.*[54]

There is a highly unequal distribution of land use between the farming of (i) animals and (ii) crops for human consumption. If we combine pastures used for grazing with land used to grow crops for animal feed, animal production accounts for 80% of global farming land with just 16% being used to grow crops for direct human consumption (4% is used to grow non-food crops such as biofuels, rubber and cotton).[51] While animals take up most of the world's agricultural land they only produce 18% of the world's calories and 37% of total protein.[52]

The Food System Economics Commission is an independent academic commission set up to equip political and economic decision-makers with tools and evidence to shift food and land-use systems. Its 2024 report entitled the *Economics of the Food System Transformation* says: 'The shift away from diets rich in animal-sourced protein is important as these diets generate extreme pressure on land'.[53] Similarly, the recent report *Appetite for Change* points out: 'No matter how efficiently animal-based food is produced, using arable land to produce feed for its production will always be less efficient than using it directly as food'.[54]

The International Grains Council (IGC) calculates that 45% of the world's grain is used as animal feed.[55] The IGC states that 956 million tonnes of grain were used as animal feed in 2017/18, while their forecast for 2025/26 is 1,096 million tonnes, which amounts to a 14% increase.[56] These figures contrast with Livestock's Long Shadow which calculates that 670 million tonnes of cereals were fed to farmed animals in 2002. This amounts to a 63% increase worldwide in the annual use of grain as animal feed between 2002 and 2025.

Our World in Data, using FAO data, states that worldwide 32 million km^2 of global agricultural land are used for grazing, with 6 million km^2 of cropland being used for animal feed.[57] This means that the amount of cropland used for feed production has grown considerably; Livestock's Long Shadow states that 471 million hectares of land (4.71 million km^2) are used for feed crop cultivation. This represents a 27% increase in the global use of cropland to provide animal feed.

Livestock's Long Shadow calculates that 33% of total arable land is used for feedcrop production. However, a 2023 study suggests that 40% of global arable land is used to provide animal feed.[58]

The above figures indicate a 63% increase in the annual amount of grain used as feed worldwide between 2002 and 2025 and a 27% increase in the amount of global cropland used to produce animal feed over a similar period. In contrast to this, FAO data show that the global area occupied by meadows and pastures fell by 151 million hectares between 2021 and 2023.[59] The FAO points out that part of the loss in permanent meadows and pastures is consistent with well-documented land degradation processes, for instance those linked to overgrazing by ruminants or climate change.[60]

The 2025 Planetary Health Check examines land system change. It states: 'transformation of natural landscapes, such as through deforestation and urbanization, diminishes ecological functions like carbon sequestration, moisture recycling, and habitats for wildlife, all crucial for Earth system health'. It identifies expansion of cropland and grazing by farmed animals as key drivers of land system change. It states: 'Modern data from satellites shows that between 2000 and 2018, nearly 90% of direct deforestation came from the spread of agriculture – around 52% for crops and 38% for grazing'. It points out: 'The impacts of forest loss are profound. It disrupts biodiversity, increases carbon emissions, alters rainfall patterns, and weakens soil and water systems'. A detailed consideration of deforestation is included in the earlier section on biodiversity loss.

4. Land and soil degradation

KEY MESSAGES

1. Globally around 1,000 million hectares of agricultural lands are degraded.
2. Between 2015 and 2019, at least 100 million hectares of fertile and productive land were degraded annually worldwide.
3. Land degradation can arise both from intensive production of grain and soy as feed for industrially reared animals - with high use of monocultures, synthetic nitrogen fertilisers and chemical pesticides - and also from overgrazing in pastures and rangelands.
4. Worldwide around one third of soils are now degraded. This erodes soil fertility and undermines its ability to store carbon and water, both of which are crucial as climate change intensifies.

Land degradation can be defined as a long-term reduction in, and loss of, land's biological productivity, ecological integrity, or value to humans. This definition is based on that provided by the International Panel on Climate Change.[61]

A 2025 study states that the FAO estimates that 1,660 million hectares globally are degraded due to human activities, with over 60% of this degradation affecting agricultural lands, including croplands and pastures.[62] This indicates that around 1,000 million hectares of agricultural lands are degraded.

Livestock's Long Shadow describes land degradation as a 'vast and costly loss'. The report calculates that about 20% of the world's pastures and rangelands, with 73% of rangelands in dry areas, have been degraded to some extent, mostly through overgrazing, compaction and erosion created by livestock action. It adds that 'the expansion and intensification of crop agriculture is associated with profound land degradation problems'.

UNEP's 2025 Global Environmental Outlook reports that between 2015 and 2019, at least 100 million hectares (the size of Ethiopia or Colombia) of fertile and productive land were degraded annually worldwide.[63]

It adds that the greatest impacts are expected in India, China and Sub-Saharan Africa, 'where land degradation could halve crop production, mainly due to the prevalence of monoculture farming systems'.

UNEP's study states: 'Agricultural expansion and intensive farming practices, which involve high pesticide and fertilizer use, are key contributors to land degradation and threaten agricultural productivity, ecosystems, and human health'. It also points out that compaction from excessive use of agricultural machinery can result in significant land degradation.[64]

Land degradation can arise both from intensive production of grain and soy as feed for industrially reared animals and also from overgrazing in pastures and rangelands. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) states: 'The increased use of intensive livestock production systems with high off-site impacts increases the risk of degradation in other ecosystems.'[65]

These 'high off-site impacts' stem from the production of feed crops which are generally produced intensively with the use of monocultures, chemical pesticides and synthetic nitrogen fertilisers. Other sections of this report look at the detrimental impacts of the use of agro-chemicals.

Monocultures are highly damaging to soil health. Growing the same crop year after year significantly harms soil quality by depleting specific nutrients, reducing biodiversity, and accelerating erosion. Growing the same crop repeatedly reduces organic matter, degrades soil structure, and diminishes beneficial microbial populations.[66] In contrast to this, growing different crops together limits soil erosion, maintains soil nutrients and improves the storage of soil carbon.[67]

Soil degradation and loss of soil biodiversity

'Humanity's continued existence is completely dependent upon six inches of topsoil and the fact that it rains': quote attributed to Confucius.

Livestock's Long Shadow identifies soil degradation as a major threat but does not quantify the extent of soil degradation. However, the 2025 Soil Atlas calculates that worldwide around one third of soils are now degraded.[68]

Soil degradation is a sub-component of land degradation, specifically referring to the decline in soil quality, health, or fertility due to physical, biological or chemical damage. Soil degradation includes erosion by wind or water, salinisation often due to irrigation, acidification as a result of excessive use of nitrogen fertilisers, compaction due to the use of heavy farm machinery, and loss of soil biodiversity owing to excessive use of pesticides and nitrogen fertilisers. The FAO states that soil 'erosion carries away 20–37 billion tonnes of topsoil annually, reducing crop yields and the soil's ability to store and cycle carbon, nutrients and water'.[69]

Agriculture is completely dependent on healthy soils. Fertile soil is needed to produce good yields. Soil organic matter is a key component of good soil; it builds fertility and stores (sequesters) carbon so helping to reduce greenhouse gas emissions. The myriad organisms in soil organic matter (such as earthworms, spiders, mites, bacteria, fungi) decompose plant residues, turn them into humus, and distribute this fertility-giving substance throughout the soil (so minimising the cost of and dependence on synthetic fertilisers).[70] Soil with plentiful organic matter is able to retain water thereby preventing or reducing flooding and mitigating droughts.

The FAO states that 'Soils are considered among the most biologically diverse habitats on Earth. It has been estimated that 1 gram of soil contains up to 1 billion bacteria cells, comprising tens of thousands of taxa and a wide range of organisms including nematodes, earthworms and arthropods'.[71] The FAO points out 'There are more living organisms in a tablespoon of soil than there are people on Earth'.[72]

Cracked, parched earth © Shutterstock

The FAO indicates that agricultural intensification (which in part is driven by the huge demand for feed crops) has damaging impacts on soil biodiversity i.e. it:

- Decreases soil biodiversity with recovery of soil communities sometimes taking years or decades
- Causes smaller and less functional below-ground food webs
- Causes a loss of soil carbon and nutrients through leaching.[73]

A substantial proportion of nitrogen fertilisers are used to produce feed crops for farmed animals. A 2022 study points out that 'Applications of N [nitrogen] fertilizer can improve soil quality, but the long-term excessive application of N fertilizer can lead to the deterioration of the soil environment, alter the properties of organic matter, and affect the adsorption and accumulation of soil pollutants'.[74]

The large amounts of manure emanating from industrial animal production and the nitrogen fertilisers used to grow feed crops act as pollutants. In contrast to this, in agroecological enterprises the use of animal manure in moderate quantities can promote long-term soil health and boosts crop yields.[75] Agroecology replaces the use of synthetic fertilisers and builds soil fertility by a combination of animal manure, legumes, rotations, compost, cover crops, crop residues and reduced or no tillage.

5. Water use and pollution

KEY MESSAGES

1. Livestock's Long Shadow stated: 'The livestock sector is a key player in increasing water use mostly for the irrigation of [animal] feedcrops.'

2. The FAO states that globally, agriculture is the dominant sector in terms of freshwater withdrawals (e.g. from rivers, lakes and groundwater) representing 72% of total freshwater withdrawals in 2020. Agriculture's withdrawals are mostly for irrigating crops, a significant proportion of which is used to feed animals.

3. Water for feed production accounts for over 90% of global water withdrawals for farmed animals with just 2% being needed for drinking and cleaning animals' housing.

4. Irrigation water used annually to produce feed at the time of Livestock's Long Shadow was 108-116 km^3 per year, while this figure has now risen to 250 km^3 per year.

5. Grain-based animal feeds, which are dominant in intensive systems, require five times more blue water (irrigation) and grey water (to clear up pollution) per kg of feed than roughage-based, pastoral feeds.

Research has helpfully developed the proposition that the water footprint of animal-source foods consists of three colour-coded components: the green, blue and grey water footprint.[76] The green water footprint refers to soil moisture from naturally infiltrated rainfall on both irrigated and rainfed agriculture land; the blue water footprint refers to the volume of surface and groundwater consumed in the production of the food; this will mainly be water taken from surface water (rivers and lakes) and groundwater to irrigate cereals and soy grown for animal feed. The grey water footprint refers to the volume of freshwater that is required to assimilate the pollutants used in the production of the feed crops e.g. pesticides and synthetic nitrogen fertilisers.

The FAO states that globally, agriculture is the dominant sector in terms of freshwater withdrawals (referred to below as 'blue water') representing 72% of total freshwater withdrawals in 2020, followed by the industrial sector at 16% and municipal use at 12%.[77] Agriculture's withdrawals are mostly for irrigating crops, a significant proportion of which is used to feed animals.[78]

The FAO adds: 'While overall growth in water withdrawal is slowing, agricultural water withdrawal continues to rise, reflecting the continuous increase in areas under irrigation. The rapid rise in levels of water withdrawal over the past decades has resulted in a growing number of regions becoming subject to increased water stress.'

Livestock's Long Shadow stated: 'The livestock sector is a key player in increasing water use, accounting for over 8% of global human water use, mostly for the irrigation of feedcrops. It is probably the largest sectoral source of water pollution, contributing to eutrophication, "dead" zones in coastal areas [and] degradation of coral reefs. The major sources of pollution are from animal wastes, antibiotics and hormones, fertilizers and pesticides used for feedcrops, and sediments from eroded pastures.' The issue of water pollution is examined in more detail in the below sections on nitrogen and phosphorus.

Livestock's Long Shadow points out that water-use for drinking and servicing (e.g. to clean the animals' housing) is only a small part of an intensive animal farm's use of water. Hoekstra (2020) calculates that water for drinking and servicing count for 1.1% and 0.8% respectively of the water used to produce animal-source foods. The vast majority of an animal farm's use of water arises from the production of feed; Hoekstra (2020) states: 'The water footprint of feed contributes 98 per cent to the water footprint of meat and dairy.'[79] A 2024 study reports that 'feed production water accounts for the majority (>90%) of global livestock water withdrawals, though there is regional variation'.[80]

Livestock's Long Shadow calculates that 81-87 km^3 of evapotranspired irrigation water were used annually to produce barley, maize, wheat and soybean meal for livestock feed. The study states that these four crops represent three quarters of the feed given to managed farmed animals. This suggests that if all crops used as feed were taken into account, the evapotranspired irrigation water used annually to produce feed at the time of Livestock's Long Shadow would have been 108-116 km^3.

Recent figures indicate that the amount of freshwater used globally for farmed animals has risen considerably since publication of Livestock's Long Shadow. Heinke et al (2020) state that 4,387 km^3 of blue and green water are used annually to produce feed for farmed animals, of which 94% is green water.[81] This indicates that 263 km^3 of blue water are used annually to produce feed. Wisser et al (2024) calculate that 251 km^3 of blue water are consumed annually by the global animal farming sector in the form of evapotranspiration from feed crops.[82]

Livestock's Long Shadow points out that the use of rainwater (green water) in the raising of animals on grassland is often not problematic as that rainwater may have no opportunity cost – it would not be used for any other economic purpose. However, it adds that the land, rather than the water, may have an opportunity cost. Arguably, some grazing land should be released to support natural climate solutions such as restoration of forests and peatland.[83]

Intensively farmed animals, however, are fed on concentrates which comprise large amounts of grain and soy. These crops are grown on arable land that in some cases will be irrigated and where pesticides and synthetic fertilisers may well be used i.e. there will be large blue and grey water footprints in the production of concentrate feed for intensively farmed animals.

Livestock's Long Shadow adds that even where rainwater (rather than irrigation water) is used to grow animal feed crops on arable land, there is an opportunity cost as that rainwater (and the arable land) could be used much more efficiently to grow crops for direct human consumption.


Irrigation of soybeans – 76% of global soy production is used to feed farmed animals © Shutterstock

Mekonnen and Hoekstra's landmark 2012 paper provided a detailed analysis of the green, blue and grey water footprints of several animal products.[84] They concluded that:

- Animal products from industrial systems generally consume and pollute more ground- and surface-water resources [i.e. blue and grey water] than animal products from grazing or mixed systems;
- The anticipated further intensification of animal production systems globally will result in increasing blue and grey water footprints per unit of animal product; the authors state that this is due to the larger dependence on concentrate feed in industrial systems;
- The water footprint of any animal product is larger than the water footprint of crop products with equivalent nutritional value;
- It is more water-efficient to obtain calories, protein and fat through crop products than animal products.

Hoekstra (2020) highlighted the difference between the blue and grey water footprints of grass-fed animals and those fed on concentrates. He said that grain-based animal feeds, which are dominant in intensive systems, require 5 times more blue water (irrigation) and grey water (to clear up pollution) per kg of feed than roughage-based, pastoral feeds.[85]

6. Nitrogen

KEY MESSAGES

1. The FAO (2025) states: 'the livestock sector is the main contributor of nitrogen losses by agriculture'.

2. The FAO adds that farmed animals are responsible for about one-third of total nitrogen emissions from anthropogenic activities.

3. Nitrogen has gone further into the Planetary High Risk Zone than any other of the factors covered by the Planetary Boundaries framework.

4. Global consumption of nitrogen fertilisers rose from 90 million tonnes in 2005 to 109 million tonnes in 2021 representing a 20% increase.

5. Industrial production of farmed animals is inherently less efficient than crop production as it entails nitrogen losses to the environment at two separate stages. First when nitrogen fertilisers are applied to feed crops and then when the compound feed containing these crops is fed to the animals.

6. Livestock's Long Shadow calculated that just around 40% of the nitrogen in fertilisers is harvested in the crops. This indicates that some 60% of the nitrogen applied to the crops is lost to the atmosphere or the hydrosphere, causing significant environmental damage. A 2025 FAO report provides broadly similar figures and estimates that around 70% of nitrogen that enters the crop system from fertilisers is lost to the environment.

7. Livestock's Long Shadow stressed that the efficiency of nitrogen assimilation by farmed animals is even lower than in the case of crops. A 2023 study indicates that, depending on the species, just 6-43% of the nitrogen in animal feed is converted into edible animal-source food. The unabsorbed nitrogen is excreted as manure.

8. The global farmed animal sector emits so much nitrogen that it single-handedly exceeds the planetary boundary for nitrogen fixation.

The FAO states: ‘the livestock sector is the main contributor of nitrogen losses by agriculture and represents about one-third of total nitrogen emissions from anthropogenic activities’.[86] The FAO adds that ‘in general, livestock decrease the overall NUE [nitrogen use efficiency] of the food production system compared with plant-based production systems, as they add additional steps in the process where nitrogen can be lost to the environment’.[87]

Nitrogen in its gaseous form (N_2) makes up the great majority (~78%) of the earth's atmosphere. Nitrogen is essential to all life. But atmospheric nitrogen is unreactive and cannot be assimilated by plants.

It must first be ‘fixed’ by nitrogen-fixing bacteria in the root systems of certain plants i.e. legumes. Legumes include clover, peas, beans, soybean, and lucerne (alfalfa). Nitrogen that has been fixed is reactive nitrogen and can be used by plants.

Since the beginning of the 20th century the Haber-Bosch process enables nitrogen to be fixed chemically at high temperatures and pressures to create synthetic fertilisers. This has increased agricultural productivity but excess reactive nitrogen is environmentally damaging.
Global consumption of nitrogen fertilisers has increased from 90.64 million metric tonnes in 2005 to 109.17 million metric tonnes in 2021, representing a 20% increase.[88]

Writing in *Nature*, lead authors of the 2011 *European Nitrogen Assessment* (ENA) point out that the huge increase in reactive nitrogen put into the environment is ‘one of the major environmental challenges of the 21st century’.[89] Although nutrient inputs such as nitrogen are needed to grow crops and feed animals, nutrient losses from agricultural areas are both wasteful of a valuable resource and a major source of pollution.

Livestock’s Long Shadow states that ‘a large share of the world’s crop production is fed to animals and mineral [synthetic] fertiliser is applied to much of the corresponding cropland. Intensively managed grasslands also receive a significant portion of mineral fertiliser.’

‘some believe that nitrogen is the world’s largest externality, exceeding even carbon’

World Bank (2023), *Detox Development*

Farmed animals’ double burden of nitrogen losses

The inefficiency of using nitrogen fertilisers to grow animal feed crops

Livestock’s Long Shadow points out that crop, and especially animal, production use nitrogen at a rather low efficiency rate. Indeed, animal farming is inherently less efficient in its use of nitrogen than crop production. This is because industrial animal production involves a double burden of nitrogen losses: firstly when fertilisers are applied to feed crops and then when the compound feed containing these crops is fed to animals.

Livestock’s Long Shadow estimated that 20-25% of global synthetic fertilisers are used to produce feed for the livestock sector. The study calculated that just around 40% of the nitrogen in the fertilisers is harvested in the crops; this is a very low efficiency rate. This indicates that some 60% of the fertiliser applied to the crops is lost to the atmosphere or the hydrosphere, causing significant environmental damage.

A 2025 FAO study states that the current mean global efficiency with which nitrogen is recovered in (food and feed) crops is 48%, whereas for cereals (which are a major component of compound animal feed) the global average is 35%.[90] The FAO study states that it is estimated that around 70% of nitrogen that enters the crop system from fertiliser is lost to the environment.

Little of the nitrogen in animal feed is retained in meat, milk and eggs; most is excreted in their manure

Livestock's Long Shadow said that the IPCC (1997) calculated that the retention of nitrogen in animal products, i.e., milk, meat, wool and eggs, generally ranges from about 5 to 20% of the total nitrogen intake. Efficiency varies considerably between different animal species and products. According to estimates by Van der Hoek (1998) global nitrogen efficiency is around 20% for pigs and 34% for poultry.[91]

In 2025 the FAO said that on average 60-70% of the nitrogen fed to industrially farmed pigs is excreted through manure.[92] A 2023 study indicates that, depending on the species, just 6-43% of dietary nitrogen is converted into edible animal-source food.[93] The unabsorbed nitrogen is excreted as manure either on pastures or in the animals' housing.

Nitrogen has gone further into the Planetary High Risk Zone than any other of the factors covered by the Planetary Boundaries framework.[94]

A 2020 paper states that the global farmed animal sector emits 65 Tg (teragrams) of nitrogen annually, 68% of which is associated with feed production.[95] The 2025 Planetary Health Check (PHC) sets the planetary boundary for nitrogen fixation at 62 Tg of nitrogen per year; this includes both synthetic nitrogen fertilisers and biological fixation through leguminous plants. The PHC shows the boundary is being greatly exceeded with over 160 Tg of nitrogen being used in agriculture in 2020.

te Wierik et al (2025) focus not on nitrogen fixation but on nitrogen surplus i.e. that amount of nitrogen that is applied (by synthetic fertilisers and biological fixation) that is not absorbed by either crops or animals.[96] te Wierik et al propose a boundary of 57 Tg of nitrogen per year but calculate that in fact the current agricultural surplus amounts to 119 Tg per year. They suggest that the agricultural nitrogen surplus should be brought back from 119 Tg per year to the planetary boundary value of 57 Tg per year, a value associated with an agricultural nitrogen input reduction from 233 to 134 Tg nitrogen per year.

Crucially, research shows a very substantial increase between 2000 and 2020 in global anthropogenic nitrogen fixation in agriculture; this increased from 120 Tg in 2000 to over 160 Tg in 2020, through fertiliser application and biological fixation on all croplands.[97]

Fertiliser being applied to farmland © Shutterstock

The nitrogen that is not absorbed by feed crops nor by the animals pollutes the environment; for example, it is washed into rivers and lakes, damaging aquatic and marine ecosystems and leaches from the soil into groundwater, contaminating sources of drinking water.

The 2023 report *Appetite for Change* confirmed the findings in Livestock's Long Shadow regarding the dangers of surplus nitrogen.[98] It stresses that leakage of nitrogen from food systems threatens the environment and human health. It states: 'current [global] production levels of livestock alone exceed planetary boundaries for nitrogen'.

It adds: 'The previous report 'Nitrogen on the Table' prepared by the Expert Panel on Nitrogen and Food highlighted that high levels of reactive nitrogen emissions are linked to intensive livestock production and a high share of animal products in the human diet.' It emphasises that plant-based diets correlate with lower nitrogen footprints and positive health outcomes.

The detrimental environmental and health impacts of surplus nitrogen

The World Bank report *Detox Development* highlights the low efficiency use of nitrogen fertilisers.[99] It states: 'According to an average of 13 global databases, of the 161 teragrams of nitrogen applied to agricultural crops, only 73 teragrams of nitrogen reach the harvested crop (Zhang et al. 2021)'. The report points out that the nitrogen that is not absorbed by crops 'gets lost to the surrounding environment in its multiple chemical forms—as nitrites and nitrates, polluting the waterways; as anhydrous ammonia or nitrogen oxide, worsening air quality; and as nitrous oxide, exacerbating climate change and stratospheric ozone depletion'.

The World Bank report states: 'Science suggests that the world may have surpassed the planetary boundaries for nitrogen, and some believe that nitrogen is the world's largest externality, exceeding even carbon'.

Ailing waters

In a section headed 'Ailing waters' the World Bank report states: **'The massive increase in nitrogen fertilizers has left a scar across many of the world's water bodies**. … Runoff of excess nitrogen increases concentrations of nitrate and nitrite in the waters. These concentrations can lead to cyanobacteria-related algal blooms. … Large algal blooms can devastate ecosystems, often resulting in hypoxia or dead zones, a condition that arises when water bodies lack sufficient oxygen. The legacy effects of nitrogen pollution on the environment can also endure decades after nitrogen inputs have ceased, with long time lags between the adoption of conservation measures and any measurable improvements in water quality'.

Air pollution

The World Bank report states: **'Fertilizer is a key culprit in nitrogen pollution, which fouls the air and water worldwide'**. The report points out that some of the nitrogen applied as fertilizers ends up in the atmosphere where it is a key cause of air pollution, as it contributes to the formation of fine particulate matter that adversely affects human health.

'Fertilizer overuse continues to overload land and water with nitrogen and phosphorus, causing pollution and dead zones with no improvement in sight'

Planetary Health Check, 2025

7. Water pollution

KEY MESSAGES

Crops grown as animal feed absorb less than half the nitrogen in the fertilisers that are applied to them. Industrial animal farms produce huge amounts of manure which contains unabsorbed nitrogen. The nitrogen that is not absorbed by crops and animals can run off into rivers and lakes causing eutrophication which can kill fish and other aquatic organisms. The unabsorbed nitrogen can leach into groundwater contaminating sources of drinking water. It can also result in dead zones in coastal waters.

The nitrogen in fertilisers and animal feed that is not absorbed by the crops or the animals is one of the key causes of water pollution as it runs off or leaches to pollute rivers, lakes and groundwater. This is the 'grey water' referred to in the earlier section on water.

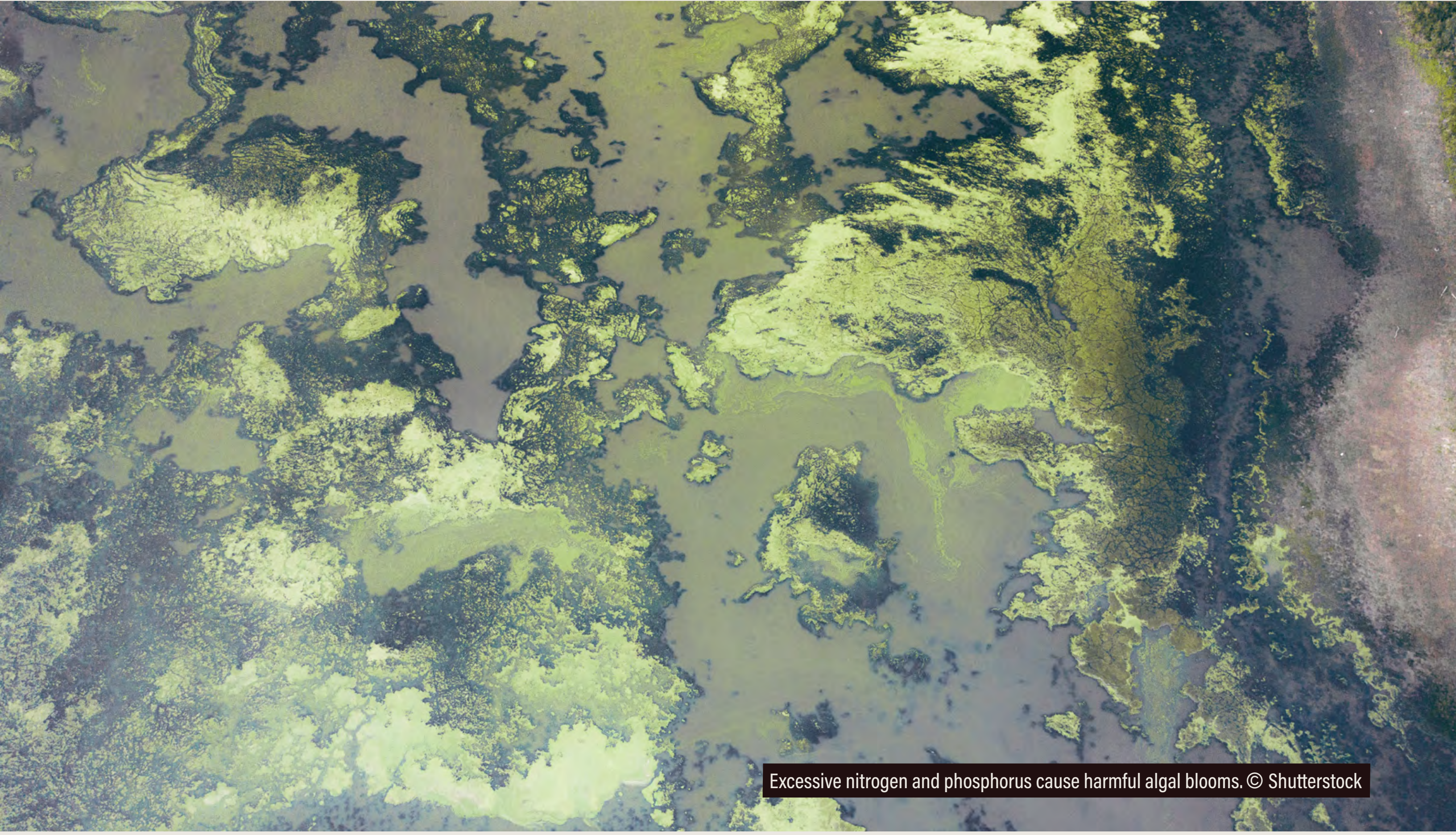
Livestock's Long Shadow estimates that every year 8.3 million tonnes of nitrogen and 1.5 million tonnes of phosphorus coming from manure end up contaminating freshwater resources.

te Wierik et al (2025) examine this issue using teragrams (Tg). Teragrams and million tonnes are the same quantity; one teragram equals one million tonnes. They state that around half of the nitrogen input on agricultural lands is taken up by plants, while 119 Tg nitrogen per year remains as agricultural surplus which, together with other nitrogen sources, ends up in surface water (70 Tg nitrogen per year), leaches to groundwater (56 Tg nitrogen per year) and is deposited on terrestrial ecosystems (20 Tg nitrogen per year).

In rivers, lakes and marine waters, excessive volumes of nitrogen – and phosphorus – stimulate the growth of algae. At moderate levels, algae serve as food for aquatic organisms, including fish. However, in a process known as eutrophication, large amounts of algae – known as algal blooms – lead to the depletion of oxygen in water. These blooms block sunlight from submerged plants which leads to them dying and, as they decay, they consume large amounts of oxygen making it impossible for fish and other aquatic organisms to survive.

Surplus nitrogen from fertilisers and manure can leach through soils into groundwater which can result in nitrate concentrations in drinking water that exceed safety standards.

Dead zones: In marine ecosystems the excess nitrogen leads to a surge in plant growth. When these die their decomposition consumes oxygen, leaving areas largely depleted of oxygen. The body of water can no longer support fish and other life and becomes a 'dead zone', destroying the livelihoods of fisherfolk.



Excessive nitrogen and phosphorus cause harmful algal blooms. © Shutterstock

Gulf of Mexico Dead Zone

Livestock's Long Shadow describes the presence of a massive dead zone in the Gulf of Mexico created by huge amounts of nitrogen pouring down the Mississippi from unabsorbed nitrogen in synthetic fertilisers as well as from nitrogen in the excreta of farmed animals. The report indicates that the farmed animal sector is the leading contributor to water pollution by nitrogen in the U.S. with the Mississippi drainage basin containing almost all the U.S. feed production and industrial animal production. Map 5.2 of Livestock's Long Shadow shows a huge area in the mid-West where over 50% of cropped land is dedicated to the production of animal feed.

In 2024 the U.S. National Oceanic and Atmospheric Administration (NOAA) reported that the Gulf of Mexico's dead zone in 2024 measured approximately 6,705 square miles, the 12th largest zone on record in 38 years of measurement.[1] This figure equates to more than four million acres of habitat potentially unavailable to fish and bottom-dwelling organisms. NOAA added that the five-year average size of the dead zone is now 4,298 square miles.

[1] National Oceanic and Atmospheric Administration, 2024. Gulf of Mexico 'dead zone' larger than average, scientists find https://www.noaa.gov/news-release/gulf-of-mexico-dead-zone-larger-than-average-scientists-find

8. Air pollution

KEY MESSAGES

1. **Industrial animal production is a major source of air pollutants including ammonia. These pollutants arise both directly from manure production on farms and indirectly from the nitrogen fertilisers used to grow feed crops for animals.**

2. **Ammonia emissions from agriculture increased by 18% between 2006 and 2022.**

3. **Losses from animal manure and synthetic fertilisers account for over 80% of total ammonia emissions in, e.g. Europe, United States and China.**

Industrial animal production is a major source of air pollutants including ammonia. These pollutants arise both directly from manure production on farms and indirectly from the nitrogen fertilisers used to grow feed crops for animals.[100] When it mixes with other gases, ammonia can form particulate matter which is a major cause of air pollution. Air pollution is a serious problem for human health as it contributes to bronchitis, asthma, lung cancer and congestive heart failure. In some countries – including Denmark and the UK – agriculture has been responsible for a larger proportion of the health problems arising from air pollution than transport or energy generation.[101] [102]

A 2021 paper reports that of the 15,900 annual deaths in the U.S. that result from food-related fine particulate matter pollution, 80% are attributable to animal based foods both directly from animal production and indirectly from growing animal feed.[103]

Livestock's Long Shadow reported that global anthropogenic atmospheric emissions of ammonia had recently been estimated at some 47 million tonnes (Galloway et al., 2004). It said that some 94% of this is produced by the agricultural sector with the livestock sector contributing about 68% of agriculture's share, mainly from deposited and applied manure. Data provided by the Emissions Database for Global Atmospheric Research (EDGAR) show that the amount of ammonia produced globally and the amount provided by the agriculture sector rose by 17.8% and 18.6% respectively between 2006 and 2022; see Table 2.

Table 2: Comparison of EDGAR ammonia figures for 2006 and 2022

	2006	2022
Total global ammonia emissions from all sectors: tonnes (t)	48,639,957.55	57,317,902.76
Agriculture-related ammonia emissions (t)	42,533,136.53	50,453,649.94
Agriculture-related ammonia emissions: % of total global ammonia emissions	87%	88%
Agricultural soils (t)	30,606,693.50	36,168,856.10
Manure management (t)	10,576,845.48	12,485,074.90

Source: EDGAR (Emissions Database for Global Atmospheric Research) Community GHG Database. Air and toxic pollutants. https://edgar.jrc.ec.europa.eu/air_pollutants

Two recent studies calculate that agriculture contributes over 81% of total global ammonia emissions.[104] [105] Van Damme ***et al***. (2021) report that volatilization from animal manure and losses from synthetic fertiliser application account for over 80% of the total ammonia emissions in, e.g. Europe, United States and China.[106] As a substantial proportion of synthetic fertilisers are used to grow feed crops, it is clear that farmed animals are a major contributor to ammonia emissions.

9. Phosphorus

KEY MESSAGES

1. **As with nitrogen, farmed animals are responsible for substantial amounts of unabsorbed phosphorus that cause significant ecological degradation. This is a two-stage process: first, cereal crops grown as animal feed only absorb a small amount of the phosphate fertilisers applied to them and, secondly, animals typically retain less than 30% of the phosphorus that is in their feed – the rest is excreted in their manure.**

2. **As with nitrogen, unabsorbed phosphorus can run off into rivers, lakes and marine ecosystems where it can form harmful algal blooms leading to the death of fishes and other aquatic organisms. It can also leach into groundwater potentially contaminating drinking water supplies.**

3. **The intensive animal sector has a Phosphorus Use Efficiency (PUE) of just 18% compared to a PUE of 46% for the overall agricultural system.**

4. **The production of meat, milk and eggs requires much greater use of phosphorus fertilisers per unit of food delivered than the production of crops for direct human consumption.**

5. **The 2025 Planetary Health Check states that phosphorus application continues to be in the High Risk Zone 'with worsening trends'.**

A detailed study entitled *Our Phosphorus Future* states: 'Agriculture is entrenched in its reliance on mineral phosphorus fertiliser; 85% of phosphates produced for the market are processed to make mineral fertilisers and 10% are used to make animal feed supplements'.[107]

Global annual use of phosphate fertilisers has increased from 5.0 teragrams (Tg) (1 Tg = 1 million metric tonnes) in 1961 to approximately 25 Tg in 2020 and is expected to reach 27 Tg in 2050.[108]

Phosphorus losses from animal farming are a two-stage process

As with nitrogen, farmed animals are responsible for substantial amounts of unabsorbed phosphorus that causes significant ecological degradation. This is a two-stage process: first, cereal crops grown as animal feed only absorb a small amount of the phosphate fertilisers applied to them and, secondly, animals only retain a small proportion of the phosphorus that is in their feed. Farmed animals obtain phosphorus from the natural and fertiliser-based phosphorus present in cereals and also from phosphates added directly to their feed.

A 2024 study found that just 12.6% of applied phosphate fertilisers are taken up by plants, 67.2% of phosphate fertiliser is stored in soils and 4.4% is lost via run-off or leaching.[109] Another study focussed on cereal crops which are the crops that are the main ingredient in animal compound feeds. Similar to the 2024 study, this study found that cereals absorb just 12.4% of the phosphorus in fertilisers that is applied to them.[110]

The study *Our Phosphorus Future* states: 'livestock are commonly fed more phosphorus than they can utilise, leading to excretion of phosphorus-rich manures; they typically retain less than 30% of the phosphorus ingested'.

As with nitrogen, unabsorbed phosphorus can run off into rivers, lakes and marine ecosystems where it can form harmful algal blooms leading to the death of fishes and other aquatic organisms.[111] It can also leach into groundwater potentially contaminating drinking water supplies.

Animal farming sector has much lower 'Phosphorus Use Efficiency' than production of crops for direct human consumption

The low Phosphorus Use Efficiency (PUE) of the animal farming sector is highlighted by a 2021 paper that studies a range of countries worldwide.[112] This found a PUE of 46% for the overall agricultural production system, but a PUE of just 18% for the livestock subsystem and 72% for the crop-pasture subsystem. In this study the livestock subsystem accounts for the intensive farming of animals as well as associated activities, processes, and flow of materials; it does not include any crop or pasture production.

This study states: 'This analysis indicates that using a higher fraction of crop/pasture products as grazing pasture/feed instead of food will lead to lower PUE in the overall agricultural production system because the majority of feed consumed by livestock ends up in manure. In other words, applying mineral P [phosphorus] fertilizers for pasture/animal feed production and feeding that to livestock for producing animal based food (e.g., meat) may create more chances of P loss (e.g., as erosion/runoff from soils, and as manure) than applying mineral P fertilizers just for producing crop based food for humans.'

Our Phosphorus Future states that the production of meat, dairy and eggs requires disproportionately high amounts of mineral phosphorus fertilisers. For example, up to 16 times more phosphorus (and other resources) is required to produce a unit of beef from a concentrated animal feeding operation than to produce plant-based proteins.[113] The study adds that over the last 60 years, 38% of the increased use of mineral phosphorus fertilisers can be attributed to global diet changes. It states: 'This increase is predominantly related to increased consumption of animal products (meats like beef, poultry and pork, as well as milk and eggs)'. Table 3 reproduces data from *Our Phosphorus Future* that shows that a kilo of phosphorus produces much greater amounts of plant food than animal-source food.

Table 3: the amount of different foods produced by one kilo of phosphorus

Food types	One kilo of phosphorus is associated with the production of:
Starchy roots	3333 kg
Pulses	2500 kg
Fruits	2000 kg
Vegetables	769 kg
Cereals	344 kg
Milk	232 kg
Eggs	79 kg
Poultry	52 kg
Pork	31 kg
Beef	16 kg

Source: Brownlie et al., 2022. Our Phosphorus Future

Major reductions in phosphorus use are needed to return to a safe operating space

The 2025 Planetary Health Check states: 'phosphorus application is about 18.2 Tg P/year (triple the 6.2 Tg P/year Planetary Boundary)'. It adds that phosphorus application continues to be in the High Risk Zone 'with worsening trends'.

Food systems are on their own responsible for greater annual phosphorus losses to surface water than the planetary boundary. te Wierek et al (2025) state that annual phosphorus losses to surface water amount to 9.7 TgP year which is substantially higher than the planetary boundary of 6.1 TgP year for phosphorus losses to surface water.

te Wierek et al (2025) state that food systems contribute 7.2 TgP year to annual phosphorus losses to surface water which is around 75% of overall phosphorus losses to surface water and argue that therefore phosphorus loss from agricultural land should be reduced proportional to its 75% share (that is, from 7.2 to 4.6 TgP year from agricultural soils), reducing both the risk of surface water eutrophication and soil fertility loss. A food system boundary of 4.6 TgP yr would enable the food system to play its part in enabling a return to a safe operating space.

10. Pesticides

KEY MESSAGES

1. The production of animal feed is a major driver of the high global use of pesticides.
2. Livestock's Long Shadow found that in 2001 in the U.S. 37% of total agricultural use of pesticides was for feed production (soybean and corn). The report added that in the U.S. 'in 2001, 70% of the volume of herbicides [which are just one form of pesticides] used in agriculture can be attributed to animal feed production in the form of soybean and corn.'
3. Total pesticides use in agriculture in 2023 was 3.73 million tonnes of active ingredients, a 14% increase in a decade, and a doubling since 1990.
4. It is estimated that around 44% of the highly hazardous pesticides sold worldwide in 2018 were sprayed on just two crops: soybeans and maize/corn, and 76% of global soy production and 56% of the world's maize production are used as animal feed ingredients.

UNEP points out that 'The toxic effects of pesticides harm more species than those targeted. Like fertilizers, they can eventually reach water bodies and reduce their biodiversity'.[114]
Livestock's Long Shadow stated that several hundred different pesticides are used for agricultural purposes around the world with pesticide contamination of surface water resources being reported worldwide. Regarding the U.S., the report found that 37% of total agricultural use of pesticides in 2001 was for feed production (soybean and corn). Moreover, the report said that in the U.S. 'in 2001, 70 percent of the volume of herbicides [which are just one form of pesticides] used in agriculture can be attributed to animal feed production in the form of soybean and corn.'

Moreover, the report said: 'We can assume that the role of livestock production systems in pesticide use is equally important in other main feed producing countries, including Argentina, Brazil, China, India and Paraguay.' It added: 'Although it may not be possible to isolate [the] impacts on water resources or to draw conclusions on their magnitude, the use of pesticides for feed grain and oilseed production in the United States undoubtedly has major environmental impacts on water quality as well as on water-related ecosystems'.

More recently, in 2018 an estimated 235 million pounds of herbicides and insecticides were applied in the U.S. to the corn and soybeans grown for farmed animal feed.[115]

Total pesticides use in agriculture in 2023 was 3.73 million tonnes of active ingredients, a 14% increase in a decade, and a doubling since 1990.[116]

Currently, a substantial proportion of pesticides are used to grow animal feed crops.[117] It has been estimated that around 44% of the highly hazardous pesticides sold in 2018 were sprayed on just two crops: soybeans and maize,[118] and 76% of global soy production[119] and 56% of the world's maize production[120] are used as animal feed ingredients.

Pesticide use contributes to the problem they are meant to address

The FAO points out that 'conventional agriculture with low crop diversity and extensive use of pesticides tends to reduce soil biodiversity, unbalance the ecosystem with an oversimplification of the species present and pave the way for pathogenic organisms to prevail'.[121] In effect pesticides contribute to the very problem they are intended to address.

Monocultures result in proliferation of pests and pathogens

The FAO adds that monocultures, which are at the heart of intensive crop production, 'result in proliferation of above-ground and below-ground pests and pathogens, which require introduction of pesticides in intensively managed fields'.[122]

So, intensive farming contributes to a problem – proliferation of pathogens and pests – and then tries to tackle the problem with a solution – chemical pesticides – that in turn creates further problems.

The European Commission states: 'The use of chemical pesticides in agriculture contributes to soil, water and air pollution, biodiversity loss and can harm non-target plants, insects, birds, mammals and amphibians'.[123]

A report by Hilal Elver, former UN Special Rapporteur on the right to food stresses that pesticides 'cause an array of harms'. The report points out that pesticides harm wildlife, lead to declines in populations of bees and other pollinators, kill the beneficial insects that are the natural enemies of pests, and undermine soil biodiversity. In addition, they are linked to a range of negative impacts on human health.

Delivery of concentrate feed to pigs confined in standard barren industrial farm. © CIWF

HIGH NOON FOR LIVESTOCK'S LONG SHADOW

At noon, with the sun overhead, there is almost no shadow. This paper will now examine some of the ways in which livestock's lengthening shadow can be reduced.

I. Reducing production and consumption of animal-source foods

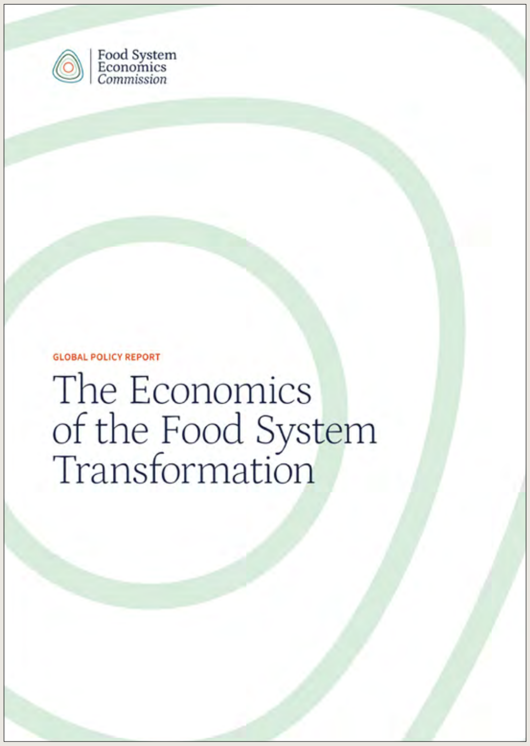
Some argue that the environmental problems arising from increasing global production of farmed animals can be addressed through technological measures designed to improve efficiency. However, such measures are unlikely to be sufficient to shrink the scale of animal farming's impacts to a sustainable level.[124]

If we are to tackle climate change, biodiversity loss and other environmental crises, consumption of animal-source foods needs to be reduced, particularly in over-consuming countries.

The *Global Environment Outlook* published in 2025 by the UN Environment Programme states that addressing unsustainable production and consumption of animal-source foods, as well as food losses and waste, would free up large areas currently dedicated to feed and food production, enabling the land system to be a net carbon sink and for ecosystems to be conserved.[125]

A report entitled *The Economics of the Food System Transformation*[126] examines the shifts in diet needed to tackle what it refers to as the global climate, nature and health emergencies. It states:

'While over- and under-consumption now occur across high-, medium- and low-income regions, on average, high- and middle-income regions need to reduce their per capita intake of animal-sourced food by 68 percent and 62 percent respectively from 2020 to 2050, and increase their intake of fruits, nuts, vegetables, and legumes … low-income regions [need to] see a 33 percent aggregate decline in the intake of animal-sourced foods under FST [the Food System Transformation] even though their intake by currently undernourished groups in those regions should increase to improve health.'



The World Bank report *Recipe for a Liveable Planet* states: 'High-income countries should decrease their own consumer demand for emissions intensive, animal-source foods. They can influence consumption by ensuring that the environmental and health costs borne by society are fully included in food prices.'


Broiler chickens packed into shed. Bred to grow so quickly that many suffer from painful leg disorders. © CIWF

II. True cost accounting

The bleak lives imposed on industrially farmed animals are justified by the assertion that this gives us cheap food. And indeed, industrially produced meat and milk are cheap at the supermarket checkout. But the low price of these products is achieved only by an economic sleight of hand. We have devised a distorting economics which takes account of some costs such as housing and feeding animals but ignores others including the detrimental impact of industrial agriculture on human health, natural resources and wildlife as well as the farmed animals themselves. The costs arising from these detrimental impacts should be internalised in the price of food. If this were done nutritious, humane, sustainable food may well be cheaper than unhealthy, inhumane food that damages natural resources.

This problem is highlighted by the UN Food and Agriculture Organisation which says: ‘In many countries there is a worrying disconnect between the retail price of food and the true cost of its production. As a consequence, food produced at great environmental cost in the form of greenhouse gas emissions, water pollution, air pollution, and habitat destruction, can appear to be cheaper than more sustainably produced alternatives.’[127]

These various detrimental impacts are referred to as ‘negative externalities’. They represent a market failure as the costs associated with them are not included in the prices paid by farmers for damaging inputs or the prices paid by consumers of animal products. Instead these costs are borne by third parties or society as a whole. In some cases the costs are borne by no-one and key resources such as soil and biodiversity are allowed to deteriorate

Prices shown in Penny supermarket in Berlin. The lower price is what consumers are charged. The higher figure shows what the price would be if the environmental harms involved in producing the meat were included in the price. The costs included in the higher price are the impact of nitrogen, GHGs, energy production and land-use change.

thereby undermining the ability of future generations to feed themselves.

An editorial in the journal *Nature* stated that the global 'food industry, especially, bears responsibility for the fact that 680 million people are obese, but it is largely governments and their citizens who have to pick up the costs of treatment'.

The editorial continues: 'When industrial-scale farms draw copious quantities of water to irrigate crops, again it is taxpayers who foot the bill for the water scarcity that can follow. It's the same for agrochemicals and their effects on the health of people and ecosystems. Governments find themselves shouldering the costs of biodiversity loss, and mopping up agriculture's contribution to greenhouse-gas emissions.'[128]

Indeed, the World Bank report *Detox Development* regards the fact that agriculture does not have to pay for the environmental harms that it causes as 'implicit subsidies'.[129] The report states: 'while explicit subsidies are large, implicit subsidies, which measure the impacts of uncorrected externalities, are even larger and represent some of the most challenging environmental problems today'.

We need to move to an economics that accurately reflects all relevant costs and internalises them in the price paid by farmers for inputs and in the price paid by consumers of animal products. The report *The Economics of the Food System Transformation* states that the unaccounted environmental costs of current food systems 'are estimated at 3 trillion USD a year and reflect the negative impacts of today's food systems on ecosystems and climate, including the impacts of current agricultural land use and food production practices'.[130]

The World Bank report *Recipe for a Liveable Planet* states: 'Full-cost pricing of animal-source food to reflect its true planetary costs would make low-emission food options more competitive'.[131]

Olivier De Schutter, former UN Special Rapporteur on the right to food, has said that 'any society where a healthy diet is more expensive than an unhealthy diet is a society that must mend its price system'. This applies equally to a society where food that respects natural resources is more expensive than environmentally damaging food.

So how do we mend our price system in order to incentivise a move to forms of agriculture that operate within the planetary boundaries?

Many bodies and reports have recommended using taxation to rebalance our food system.[132, 133, 134, 135] The use of taxation should be based on two interlocking principles:

- Internalisation of the costs generated by unsustainable farming methods and diets
- Provision of sufficient incentives and disincentives to promote systemic change.

Taxation should not be viewed as a 'sin tax' or a negative factor as the revenue raised can – and indeed must – be used to subsidise the price of nutritious, environmentally friendly food and to support farmers who operate to high standards. There must be no overall increase in the price of food, simply a rebalancing of the relative costs of sustainable and unsustainable food.

III. Repurposing harmful subsidies

The World Bank Group report *Detox Development* calculates that global agricultural subsidies exceed an estimated US$635 billion per year.[136] The report points out that many agricultural subsidies are environmentally harmful and provides key examples of such subsidies. A UNEP report calculates that globally around US$400 billion of environmentally harmful subsidies are provided annually in the agricultural sector.[137]

Detox Development stresses that 'Subsidies incentivize excessive fertilizer usage to the extent that it suppresses agricultural productivity, degrades soils and waterways, and damages people's health. More than half of global agricultural production now occurs in regions where fertilizer is suppressing rather than increasing productivity. This means there is significant room to reduce fertilizer use with positive impacts on crop production. Yet the opposite is achieved by subsidies, as excessive fertilizer application is not absorbed by crops and runs off into waterways. Inefficient subsidy usage is responsible for up to 17% of all nitrogen pollution in water in the past 30 years, which has large enough health impacts to reduce labor productivity by up to 3.5%.'

Detox Development also points out that 'Agricultural subsidies are responsible for the loss of 2.2 million hectares of forest per year, equivalent to 14% of global deforestation. Agricultural subsidies in rich countries are driving significant tropical deforestation around the world. For instance, subsidies for animal farming in the United States drive deforestation in Brazil by increasing the demand for soybeans as feedstock. In turn, subsidy-driven deforestation causes the spread of vector-transmitted diseases—including 3.8 million additional cases of malaria each year, with an economic impact of up to US$19 billion per year.'

A report published by the FAO, UNEP and UNDP (the UN Development Programme) is entitled ***A** Multi-Billion-Dollar Opportunity* and is subtitled 'Repurposing agricultural support to transform food systems'.[138] The report stresses that agricultural subsidies 'are actively steering us away from achieving the SDGs and the goals of the Paris Agreement'.

The report finds that unhealthy products and emission-intensive commodities such as beef and milk receive the most support worldwide, and highlights the 'disincentives this support creates towards producing healthier and more nutritious foods, such as fruits and vegetables'. The report argues that agricultural subsidies should be repurposed towards supporting healthier, more sustainable agriculture. The next section of this report indicates what this agriculture could look like.

IV. Producing food within the planetary boundaries

> **'High-input, resource-intensive farming systems, which have caused massive deforestation, water scarcities, soil depletion and high levels of greenhouse gas emissions, cannot deliver sustainable food and agricultural production. Needed are innovative systems that protect and enhance the natural resource base, while increasing productivity. Needed is a transformative process towards 'holistic' approaches, such as agroecology, agro-forestry … and conservation agriculture, which also build upon indigenous and traditional knowledge.'**
>
> UN Food and Agriculture Organisation, 2017

Since the publication of Livestock's Long Shadow, two frameworks – Planetary Boundaries and the EAT-*Lancet* Commission – have been developed that provide detailed guidance on the core elements of sustainable food systems.

The 2025 EAT-*Lancet* report states that 'food is the single largest cause of planetary boundary transgressions, driving the transgression of five of the six breached boundaries'. It is vital that we move to forms of agriculture that enable our food systems to move back into their safe operating spaces.

The EAT-*Lancet* report proposes a predominantly plant-based diet, with moderate inclusion of animal-sourced foods. It says: 'an EAT-*Lancet* shift by 2050 would reduce land use for agriculture by 11-18%, GHG emissions by 55-67%, water use by 9%, and nitrogen and phosphorus use by 26%, compared to business-as-usual trajectories'.

Johan Rockström, who has led the development of the Planetary Boundaries framework, says: 'While CA [Conservation Agriculture] is not a panacea for all food production challenges, it is difficult to find a more ready-to-scale farm practice'. He adds: 'in spite of some knowledge limitations to date, and in spite of CA not being a panacea to all challenges, it does provide a large and necessary lever to accelerate an urgently needed global food system transition, particularly when supported by equitable local participation and empowerment'.[139]

It is widely recognised that the following have the potential to be more sustainable than industrial agriculture: high-welfare agroecology, conservation agriculture, regenerative agriculture, integrated crop-livestock production, agroforestry and silvopastoral systems. While there are important differences between these systems, they also have much in common.

Interestingly, most of the core features of such systems are identified as being sustainable in the *Common Nature Finance Taxonomy* recently produced in 2025 by the Multilateral Development Banks (MDBs).[140] This taxonomy identifies activities that contribute to the nature positive goal of reversing nature loss and supporting the implementation of the Kunming-Montreal Global Biodiversity Framework.

Activities identified as nature positive by the Multilateral Development Banks in their *Common Nature Finance Taxonomy*

The Taxonomy identifies the following agricultural approaches – none of which are compatible with industrial crop and animal production – as being nature positive and sustainable:

- **Implementing sustainable livestock practices,** such as grass-fed cattle and free-range poultry, that enhance environmental outcomes (e.g., soil health; biodiversity; reduced reliance on external inputs).

- Sourcing or producing livestock **feed with reduced environmental impacts.**

- Applying **closed nutrient-cycle systems.**

- Implementing **conservation agriculture or agroecological practices** that promote sustainable pasture management and agrobiodiversity, or scaling up **regenerative** production models, for example by integrating native tree species into cattle pastures or agro-sylvo-pastoral systems.

- Measures to **substitute meat-based proteins with plant-based protein alternatives** (e.g., promoting plant-based diets) or reformulating products to reduce demand for meat-based protein.
- Implementing **sustainable agricultural practices** (e.g., conservation agriculture; agroecology; regenerative production models) that recover or maintain native or heritage crops or agrobiodiversity.

- **Adopting diversified cropping systems** (e.g., intercropping; use of cover crops to improve resilience and soil quality; agroforestry; silvo-pastoral systems).

- Improving **soil management**, for example by:
  - Preventing or reducing soil erosion by reducing tillage; implementing conservation tillage or no-till practices; contour farming, terracing, wind breaks, grass strips, and cover crops where appropriate to the cropping system.

Small-scale poultry farmers. © Sustainable Agriculture Tanzania

- Implementing measures to prevent soil pollution from over-use of agrochemicals, salinization, acidification, or chemical contamination (e.g., green manure; legume cultivation; soil testing; integrated pest management).
- Preventing loss of soil biodiversity, soil nutrients, or organic matter (e.g., integrated nutrient management; crop rotation; integrating perennial groundcovers; composting and mulching; use of inputs that do not damage soil biota).

- **Preventing or reducing downstream eutrophication**, through reducing synthetic fertiliser use, promoting efficient fertiliser use or the use of biofertilizer or other organic solutions (e.g., compost).

- **Reducing the use of pesticides, herbicides, and other chemicals**, or promoting the use of biological solutions such as biocontrol using natural enemies of pest species.

- **Implementing regenerative agriculture** or sustainable land or water management practices to enhance biodiversity or ecosystem services.

- **Restoring natural habitat** in productive landscapes.

- **Implementing agroforestry** practices that help restore structure or composition of natural habitats.

- **Protecting remaining natural habitat features** or fragments within agricultural land (e.g., ecological corridors).

- **Increasing natural pollinators.**

- **Preserving native breeds of farmed animals** and conserving livestock genetic diversity.

Bringing farmed animals into the light: transitioning from our current linear food system towards a circular one

Farm animals can be an integral part of healthy, nature-friendly farming systems. We need to restore the link between animals and the land so that their manure can fertilise the land rather than being a pollutant.

Pasture-based systems
Good grassland systems for raising cattle and sheep do not feed grain to the animals and minimise the use of chemical fertilisers.[141] The animals are fed on grass, crop residues and root crops grown on the farm. The pasture includes legumes such as clover which can minimise the use of both nitrogen fertilisers and soy as they are rich in protein.

Pasture-based systems that rotate different species around the pasture
Industrial animal production systems are monocultures. They entail producing just one species on a farm; the farm specialises in pigs or poultry or cattle. Regenerative agriculture often includes cattle, poultry and pigs on the same pasture-based farm. The animals are regularly rotated around the farm to give the pasture time to recover. Cattle who like longer grass are followed by sheep who prefer shorter grass. Then come pigs and finally chickens. These roam freely during the day, pecking around in the grass, feeding on bugs, seeds and worms, scratching in the cow dung to find larvae. This acts to spread the manure onto the soil.

Raising pigs and poultry on by-products and food waste
Globally most pigs and poultry are farmed industrially, consuming huge amounts of cereals and soy. This is unsustainable – and unnecessary. Pigs and poultry are nature's great foragers and recyclers. They should be kept outdoors where much of their diet can come from pasture and foraging as well as by-products and food waste

such as bakery products, fruit and vegetables that are no longer suitable for human consumption. In this way animals are converting food waste and by-products into nutritious food, so recycling nutrients into the food system.[142] Already, some innovative farmers are able to provide 70% of their pigs' feed in these ways.[143]

Integrated crop-livestock systems

The EU Platform on Sustainable Finance (PSF) has described how an integrated crop-livestock system can be genuinely circular with both the nutrients for the crops and the feed for the animals being produced on-farm. The nitrogen (N) needed as nutrients for crops is primarily produced on the farm through animal manure and biological fixation, e.g. the inclusion of legumes in rotations.[144] The PSF states that a maximum of 20% of N fertilisers can be bought-in chemical fertilisers. Moreover, the number of animals raised should not exceed the farm's capacity to use their manure to fertilise crops or pasture.

The PSF proposal limits the proportion of bought-in feed such as cereals and soy to 10% of total feed. It requires a farm to grow at least 75% of any animal feed on-farm and get the rest locally/from certified sources. This 75% cannot be grown intensively; it must be either grazed, or must comprise agroecology outputs such as catch crops and cover crops.

The PSF report also requires all herbivore and poultry species to have permanent access to pasture, with pigs having permanent access to pasture or vegetated range.

The Andhra Pradesh Community Managed Natural Farming (APCNF) initiative aims to shift most of Andhra Pradesh's farmers from conventional to agroecological farming. CGIAR (formerly called the Consultative Group on International Agricultural Research) assesses that APCNF is helpful in spearheading crop diversification, integration of livestock and crop production, and ***in situ*** regeneration of soil health.[145] CGIAR adds that APCNF has improved water holding capacity, reduced the presence of weeds, and provided dietary diversity for farmers.

Agro-forestry

Agro-forestry is a key element of regenerative agriculture and can produce important environmental benefits. A recent paper that is based on many African examples highlights the benefits of combining crops, animals and trees.[146] It is entitled 'Agriculture-Livestock-Forestry Nexus: Pathways to Enhanced Incomes, Soil Health, Food Security and Climate Change Mitigation in Sub-Saharan Africa'. One of its key principles is circularity e.g. that the wastes of one component of the farm should be used as valuable inputs in another component e.g. animal manure is used to enhance soil fertility.

Silvo-pastoral systems for cattle in South America with feed available at three levels

Alongside pasture at ground level, these systems also provide shrubs (preferably leguminous) and trees with edible leaves and shoots.[147] These systems are an excellent example of how improved productivity can be achieved without intensification as because they produce more biomass than conventional pasture, they result in increased meat and milk production both per animal and per hectare. This approach and other forms of agro-forestry can reduce the competition between agriculture and forests.[148]

Representation of the benefits of agriculture-livestock-forestry nexus system to farmers. © Manono & Gichana

Silvo-pastoral systems can produce important environmental benefits.[149] The deep roots of the trees and shrubs can enhance soil structure so improving water retention and soil biodiversity while minimising soil erosion. The deep roots can also prevent nutrients from leaching into groundwater. Where the shrubs or trees are leguminous, there is no need to use synthetic fertilisers. Silvo-pastoral systems have much greater biodiversity than pasture-only systems. They are home to many more wild birds and mammals and beneficial insects such as dung beetles. The birds and larger insects are predators on ticks so reducing tick-borne disease and the need to use chemical pesticides to control the ticks.

V. From Livestock to Animals

In its 389 pages Livestock's Long Shadow makes just three references to animal welfare, apparently unbothered about the shadow we cast on their welfare.

It is now over sixty years since Ruth Harrison's book *Animal Machines* was published giving us for the first time an insight into the inhumane nature of factory farming. But now, more than ever, animals are treated as machines, being forced to endure bleak, desolate lives. We laud them as 'sentient beings' but all too often this is just a piece of window dressing making little or no difference to the lives of most of the 94 billion terrestrial farmed animals raised globally each year.

We need to develop a fresh approach to farming that genuinely treats animals as sentient beings whose needs, wants and well-being must be fully respected.

The first step on this path is to recognise that good animal welfare entails not only preventing negative factors but also providing opportunities for animals to have positive experiences – fresh air, daylight, the warmth of the sun on their backs, the feel of the breeze moving across their bodies, pleasure, confidence, a sense of control, caring for their young, being raised by their mothers.

Scientists are increasingly recognising the importance for animals' physical and mental wellbeing of being able to engage in exploration, investigation, problem solving and play.[150]

The next step along the path is appreciating that each animal is an individual with her or his own qualities and characteristics.[151] Each animal is a one-off, a unique entity. Peter Roberts, Compassion in World Farming's founder and himself a farmer, said that factory farming begins when we lose sight of animals as individuals.

Treating animals as sentient beings, though crucial, is perhaps just a way station to the real destination – regarding animals as fellow creatures. And here we need to be accompanied not just by scientific research but also by other insights into the true nature of animals.

In his book on pigs *The Whole Hog* Lyall Watson wrote 'I know of no other animals that are more consistently curious, more willing to explore new experiences, more ready to meet the world with open-mouthed enthusiasm. Pigs are incurable optimists and get a big kick out of just being.'

And in the 4th Century St Basil of Caesaria wrote 'May we realize that they live not for us alone, but for themselves and for Thee and that they love the sweetness of life even as we, and serve Thee better in their place than we in ours'.

In the film *The Last Pig*, former pig farmer Bob Comis says 'After 10 years of looking into thousands of pig eyes, I've come to understand that they're never vacant. There's always someone looking back at me. Pigs are incredibly complex beings.'

The creatures we use in farming are animals, not machines, not livestock.


Red Duroc pig grazing contentedly © Shutterstock


Pigs in overcrowded and barren industrial farm © CIWF


Egg-laying hens and roosters roaming freely © Shutterstock


Egg-laying hens in cages at a commercial farm © CIWF

Conclusion

Livestock's Long Shadow sounded clear alarms about the environmental harms arising from the global livestock sector. However, twenty years on, these warnings have been largely ignored. As a result there has been a troublesome increase in the detrimental impact of farmed animals on biodiversity, greenhouse gas emissions, land use, and land and soil degradation as well as on water use and pollution. Farmed animals are eroding the key elements – healthy soils, ample cropland, rich agrobiodiversity and sufficient water – on which future agriculture and our ability to feed ourselves depend.

The livestock sector argues that the efficiencies it has introduced are sufficient to address some of the concerns highlighted by Livestock's Long Shadow. But these efficiencies have not been able to keep pace with the huge increase in the number of farmed animals with the result that livestock's shadow is indeed lengthening.

To reduce the harmful impacts of farmed animals on the environment, a substantial decrease in animal production and consumption is needed. This is borne out by many reports.[152] [153] [154] [155]

However, change is impeded by the huge funding for industrial animal production provided by the multilateral development banks as well as by commercial banks.

Rather than funding further expansion of industrial animal farming, we call on multilateral development banks to champion high-welfare agroecology and other truly sustainable farming practices. Agroecology works in harmony with nature, nurturing and utilising natural processes to regenerate ecosystems. It does more than reduce harm: it actively enriches soil health, restores biodiversity, conserves water, and sequesters carbon. By fostering resilient landscapes and supporting smallholder farmers, it enhances yields and strengthens local livelihoods in the Global South, and builds food systems that are both productive and ecologically sound.

If we continue as we are with inexorably rising animal numbers, it will not be possible to meet the targets of the Paris Climate Agreement and the Kunming-Montreal Global Biodiversity Framework. A surging global livestock sector will also make it impossible to return many of the factors that comprise the Planetary Boundaries Framework to a safe operating space.

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