LESS IS MORE

REDUCING MEAT AND DAIRY FOR A HEALTHIER LIFE AND PLANET

Scientific background on the Greenpeace vision of the meat and dairy system towards 2050

GREENPEACE

Contents

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An Image from the Greenpeace campaign 'Too much meat in school'. Lunch menus in a typical French primary school will often include meat on a daily basis, together with milk products

Introduction
What to eat?

For millions of years on a daily basis humans have faced the same question: *What to eat?* This is a question shared both by ancestral hunter-gatherers and working parents on their way home, wondering what to feed their family. The availability of healthy food and the consequences of the choices we make today about our daily diet can be very challenging to some, and overwhelming to others. However, not only does this question have an impact on our wellbeing but also on Earth itself.

"The answer will determine what kind of future our children will have, and perhaps the destiny of our species"

Many of us in academia and civil society believe that *What to eat?* is one of the most critical questions that will help shape our future. The answer will determine what kind of future our children will have, and perhaps the destiny of our species and many of the animals, microbes and plants inhabiting planet Earth.

What we eat nourishes us and helps us to maintain a healthy life, but bad choices can also make us very sick. What food we eat, how much, and how that food is grown, is also key to the survival of our planet.

A farmer and child in a corn field, Lower Nyando - Kisumu County. Farmers in Kenya are effectively applying ecological farming practices that are increasing their ability to build resilience to and cope with climate change

"Greenpeace is calling for a global reduction of 50% in production and consumption of animal products by 2050"

The Greenpeace vision

In this report, we try to answer the question of *What to eat?* by reviewing the scientific evidence pointing at the ways in which changes to the global food system can help to achieve a healthy population and healthy planet. In particular, we focus on how reducing meat and dairy consumption and production can contribute to preserving climate, biodiversity and water systems, while improving the wellbeing of humans, now and into the future. It provides an in-depth review of current science, looking at the meat and dairy system in a holistic way. It also accompanies the shorter summary report *Less is More*[1], by providing deeper analysis and more details.

The structure of this report reflects the various threats generated by our excessive production and consumption of meat and dairy. Climate change is the clearest threat to our life on the planet requiring urgent action. For this reason, this report starts by explaining the scientific rationale for improving our dietary choices in terms of greenhouse gas emissions from the meat and dairy system (Chapter 1, page 10).

In addition to acting to prevent climate change, we must also ensure the preservation of other living creatures and ecosystems that make human life on Earth possible. We dedicate Chapter 2 (page 22) to reviewing the impacts of meat and dairy systems on the environment.

Planetary health must include the health of humans. Human health is affected by what we eat and by the global changes set in motion by trends towards increasingly meat-heavy diets. Chapter 3 (page 56) evaluates current scientific evidence on the impacts of a meat-heavy diet on human health and how changing our diets to include more plants and less meat and dairy could make us more healthy.

We conclude with recommendations and demands to governments, corporations and individuals on how we, if we act quickly and sensibly, can still ensure a green and peaceful planet on which our children can enjoy healthy lives.

This report clearly illustrates that the current livestock system is one of the sectors that will decide our future and survival on the planet. Greenpeace believes that this strong scientific evidence must translate into urgent global action. In order to protect the health of our children and of our planet for future generations from the impacts of industrial meat production2 we urgently need to start eating more plant-based food and less meat. If we choose to eat meat sometimes, the best option is to buy it from small local ecological farmers.

Greenpeace is calling for a global reduction of 50% in production and consumption of animal products by 2050 as compared to the current situation.[3] Achieving this goal is possible under a vision of ecological farming. In other words, we propose a level of production that ensures food security while protecting the climate and biodiversity.

1. The shorter report is downloadable at www.greenpeace.org/livestock_vision
2. Industrially produced meat and dairy can be defined as animal products from sources that do not respect these general principles: food security rights by competing with human food, human rights of workers in the value chain, welfare rights of animals, and environmental principles that ensure zero deforestation, a safe climate, clean water and air, and biodiversity conservation. More details can be found in the Appendix: What Greenpeace means by 'ecological livestock', page 82.
3. Please note that the latest data from FAOSTAT is year 2013 (as of January 2018), so that is the reference year for the Greenpeace goal.

Our approach to Meat and Dairy

Although not all meat types are equally harmful in terms of their contribution to climate change, degradation of the wider environment and the negative effects on human health, we conclude that the best approach is to tackle the meat and dairy sector in a holistic[1] way, including all types of animal products from both a production and consumption perspective.

Many animal products have significant negative environmental and social impacts relative to plant-rich foods. The magnitude of the impact of each food can differ in terms of the specific elements associated with it, for example, climate gases related to a per kilo unit. Other impacts are indirect and transversal, such as those that involve workers rights or animal welfare (Oxfam, 2015; Sharma & Schlesinger, 2017). Hence the suggestion that the best approach is a holistic one.

Human preferences for different animal products are undergoing significant shifts. So while chicken can be seen as less impactful than beef on a kg by kg comparison of climate emissions, the global environmental footprint of chicken production and consumption is massive. This is due to the **fast rising trend in poultry consumption and the very large absolute production and consumption volumes.**

Between 1990 and 2013, while there was a 10% decrease in global beef consumption per capita, there was a 23% increase in pork and a striking 96% increase in poultry consumption (Figure 1). The production of pigs and chickens already represents 70% of the total meat production globally. China's consumption of pigs and chicken has become globally relevant, as the country imports 20% of the total soy production exported from Brazil, as non-ruminant feed (Galloway et al., 2007). As such it is important to consider the negative environmental contribution of other meat types, besides beef, to land-use changes and deforestation linked to the production of feed, of which poultry and pork are big consumers.

In addition, growth in total meat consumption is projected to be driven largely by poultry and pork, not beef or other red meats such as sheep or goat. Poultry is expected to overtake pork as the most consumed meat in the world by 2022 (Henchion et al., 2014). Likewise, the consumption of milk and dairy products is expected to rise, with production increasing by more than 1.8% per year. This growth will be most intense in countries like China, India and Brazil (FAO, 2010a). Dairy cows are also a major consumer of feed crops.

1. Holistic: systemic approach in which the parts of something are considered to be intimately interconnected and explicable only by reference to the whole. Ecological problems usually require holistic solutions.

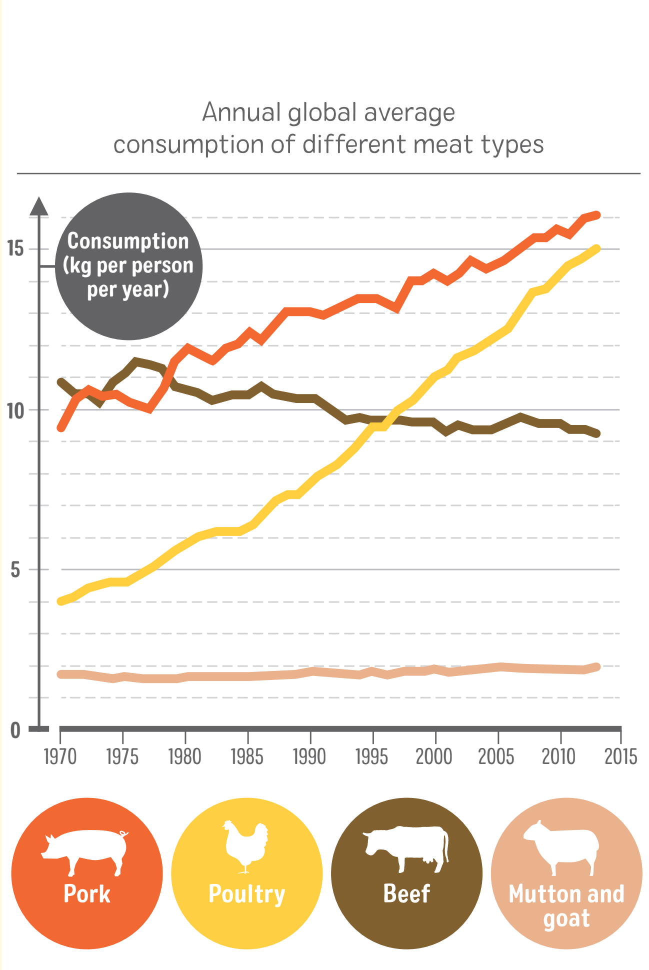


Figure 1. Global average consumption of different meat types from 1970 to 2013. These products were the major meat types consumed in kg of product per person per year (carcass weight, meaning raw unprocessed products at the point of retail sale). Data from FAOSTAT (2018)

Feed production has significant negative impacts on forests, water resources and our climate, and contributes to food insecurity where land is used to feed animals instead of feeding people directly. Conversion of feed to animal food is largely inefficient. As little as 3% of the plant calories in feed are converted into calories in beef, for example (Shepon et al., 2016).

Different types of meat have negative impacts on various key issues. While beef production has greater impact on the climate, chicken is often at the centre of foodborne infectious disease problems because of associated bacteria and other pathogens. *Campylobacter* and *Salmonella* infections account for more than 90% of all reported cases of bacteria-related food poisonings worldwide. Most of these cases are related to the consumption of poultry and poultry products (FAO, 2013). Globally, as mentioned, the increase in poultry consumption is a major component in the overall increase of all meat consumption (Kearny, 2010) and, therefore, is likely to increase in importance in relation to the causes of human disease.

Pigs in Wendland, Lower Saxony, Germany. The farm is a member of the Neuland (Newland) label, that has high standards in animal welfare and housing

"If the rate continues to hold, 76 billion animals will be slaughtered to satisfy meat and dairy consumption this year"

The number of chickens, pigs and cattle slaughtered per capita more than tripled between 1961 and 2009, reaching over ten animals slaughtered for every person on Earth in 2009. If this rate continues to hold, 76 billion animals will be slaughtered to satisfy meat and dairy consumption this year (Allievi et al., 2015). The ethical dimension of ensuring the wellbeing of all these animals is, therefore, also a very important factor that needs to be considered.

In this report we have not included seafood because our focus has been on the land-based agriculture and food systems. However, fishing is a main driver of biodiversity loss in our oceans. Overfishing and habitat destruction have significantly degraded marine ecosystems worldwide. That said, fishing plays a major role in meeting the basic needs of some of the most vulnerable communities on Earth and makes a critical contribution to global food security.

Low-impact small-scale fishing has the potential to co-exist with well-preserved ecosystems and abundant fish populations, as well as to support the lives of hundreds of millions of people. Fishing and trade policies should be designed to ensure that priority access to fish resources is granted to small-scale low-impact fishers and to vulnerable communities that depend on seafood to meet their basic nutritional needs. A large majority of global fish stocks have been fully exploited or overfished yet seafood is one of the most internationally traded food commodities. Ensuring food security for vulnerable communities will involve questioning the current appetite for fish in rich societies and diminishing fish consumption, particularly of fish products that are associated with environmental impacts.

chapter one

The Greenpeace vision for reducing the climate impact of meat and dairy

To meet the goals of the Paris Climate Agreement and ensure a safe climate by 2050, the world needs a revolution in food production, in addition to the decarbonising of all other sectors and increases in carbon sequestration.

To limit the global average temperature increase to 1.5 °C, we need to address meat production due to its current large greenhouse gas (GHG) emissions and potentially even larger contributions in the future (Bajželj et al., 2014; Hedenus et al., 2014; Rogelj et al., 2016).

According to recent scenarios on climate gases, emissions from the food system going forward to 2050 have been estimated to reach 20.2 billion tonnes of carbon dioxide equivalent (CO_2e) per year[1], including land-use change, in the baseline scenario (Bajželj et al., 2014).[2]

This means that the GHG emissions from agriculture alone **takes nearly the full 1.5 °C target emissions allowance by 2050 for all sectors, including energy, industry, transport and others (21 ± 3 billion tonnes of CO2e per year)** (Bajželj et al., 2014). This fact alone underpins the urgent need, and the opportunity, for tackling food-related emissions, particularly emissions from meat and dairy production.

Currently, direct GHG emissions from the agriculture sector account for 24% of all global emissions, and livestock emissions (including land-use change) account for 14%, which is comparable to the emissions from the whole transport sector (Smith et al., 2014).

Climate emissions from agriculture are projected to continue to increase in absolute as well as relative terms reaching 52% of global emissions in 2050, as population and economic growth brings about increases in food production and waste, as well as shifting diets towards those that are meat-heavy (Bajželj et al., 2014). 70% of these agriculture emissions will come from livestock in 2050.

Technical mitigation potential within agriculture production appears to be less effective than in other sectors, hence the need to address emissions from the food system as a whole, including both the production and consumption of animal products due to their intensity in greenhouse gas emissions (Bajželj et al., 2014).

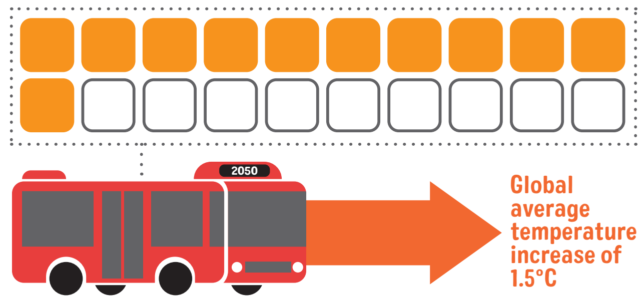
Scientists from the University of Oxford, the Swedish University of Agricultural Sciences, University of Cambridge, University of Aberdeen, University of Minnesota, University of California, Research Institute of Organic Agriculture (FiBL) and the Food and Agriculture Organization, among many other international institutions and authors, have pointed to the climate, environmental, health and economic benefits of drastically reducing livestock production and consumption (Stehfest et al., 2009; Popp et al., 2010; Hedenus et al., 2014; Tilman & Clark, 2014; Schader et al., 2015; Springmann et al., 2016a; Röös et al., 2017).

Accordingly, Greenpeace is calling for a global reduction of 50% in production and consumption of animal products by 2050 as compared to the current situation. Achieving this goal is possible under a vision of ecological farming, in other words, a level that ensures food security while protecting climate and biodiversity. This goal is

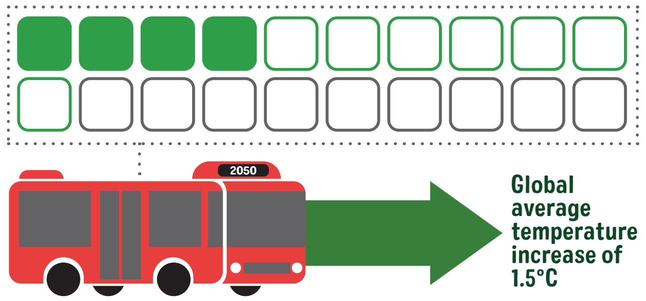
1. Billion tonnes or Gigatonnes (Gt) of carbon dioxide equivalent (CO_2e) is a unit that combines the emissions of different greenhouse gases into one unit to enable comparison because the impact of different greenhouse gases on the atmosphere is not the same. Methane (CH_4) is 25 times more potent than CO_2; nitrous oxide is 298 times as potent as CO_2. All scenarios are expressed in terms of billions of tonnes of global annual CO_2-equivalent emissions per year (Gt CO_2e yr^{-1}).
2. The baseline scenario is the Business as Usual (BAU) scenario which assumes no major changes in trajectory, so that normal circumstances can be expected to continue unchanged.

Box 1: Visualising agricultural emissions

The significance of emission reductions from our current food consumption towards a plant-rich diet can be illustrated very simply. Imagine a bus with 20 seats available for GHGs to limit global warming to 1.5°C by 2050.



Out of these 20 seats, 11 are projected to be taken by the food system, if we continue to increase meat consumption. This only leaves 9 seats for other essential sectors in our economies (energy, industry, transport and beyond). This will be a very crowded bus and probably lead to overflowing and a dangerous journey ahead.



Fortunately, **if we collectively move to a plant-rich diet, we can free up 7 seats on that bus**, thus largely increasing our chances of safely arriving at our destination in 2050. In addition, freeing up those seats will also ensure better human health due to improved diet, and a much better prospect for protecting nature.

Food system emissions in this example do not include land-use change.

The Greenpeace vision

The Greenpeace vision for ecological farming[1] is of a food system in which there is enough food for all, but one which minimises environmental damage during its production. For livestock, that means animals are reared respectfully and without suffering, using land that is not required for human food production, yet maintaining enough land for biodiversity. Recent scientific models validate this vision of feeding the world with ecologically-grown food. Reducing food waste and meat consumption are imperative for a future based on ecological food and farming (Muller et al., 2017).

Undoubtedly, we also need to address deforestation and a complete renewable energy transition in addition to food systems in order to keep climate change below unsafe levels. It must be also noted that the current industrial livestock system is considered one of the main drivers of deforestation worldwide.

Feeding animals as part of an ecological food and farming system means reducing the amount of land on which they graze and the land dedicated to growing feed, which in turn means dramatically fewer livestock animals than today. This is because land on our planet is finite, and it should be first prioritised for food security and for the health of our planet. In practical terms, ecological livestock means feeding ruminant animals on grasslands and pork and poultry on wasted food or crop residues. This system was first outlined by Fairlie (2010) as Default Livestock, and more recently also named the Ecological Leftovers model (Röös et al., 2016, 2017; Garnett, 2009). We simply refer to it as the 'ecological livestock system'' (as outlined in detail in an earlier Greenpeace Research Laboratories technical report, Ecological Livestock, Tirado & Kruszewska, 2012).

Ecological livestock rely only on grasslands, pasture and residues for feed to ensure food security and a healthy planet. This is imperative, because the current food and agriculture system is destroying our climate. At the same time there are more than 800 million people hungry and close to 2 billion overweight.

1. **Ecological farming** ensures healthy farming and healthy food for today and tomorrow, by protecting soil, water and climate. It promotes biodiversity, and does not contaminate the environment with chemical inputs or genetically engineered plant varieties. Ecological farming encompasses a wide range of crop and livestock management systems that seek to increase yields and incomes and maximise the sustainable use of local natural resources whilst minimising the need for external inputs (see Tirado, R. 2015. Ecological farming: the seven principles of a food system that has people at its heart. Greenpeace Research Laboratories Technical Report).
Ecological livestock integrates farm animals as essential elements in the agriculture system; they help optimise the use and cycling of nutrients and, in many regions, provide necessary farm working force. Ecological livestock relies on grasslands, pasture and residues for feed, minimising use of arable land and competition with land for direct human food production, and protecting natural ecosystems within a globally equitable food system (see Tirado, R. & Kruszewska, I. 2012. Ecological Livestock: Options for reducing livestock production and consumption to fit within ecological limits, with a focus on Europe. Greenpeace Research Laboratories Technical Report)

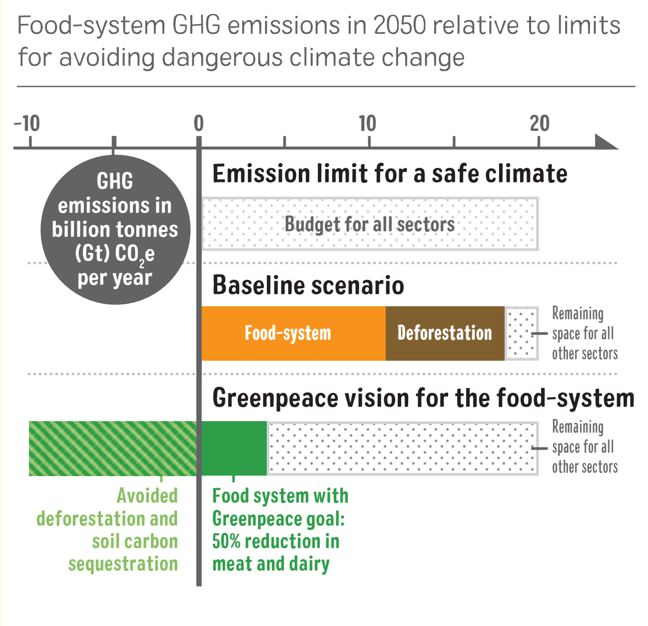


Figure 2. Food-system greenhouse gas (GHG) emissions in 2050 relative to the global limit of emissions for all sectors to address climate change in accordance with the Paris Agreement. A) The GHG budget for all sectors refers to the global amount of emissions, for all sectors combined, that would be consistent with a limiting temperature increases to 1.5–2 °C (as in Bajželj et al. 2014). B) GHG emissions under the baseline projections, Business as Usual, for food-related emissions, directly from the food system and indirectly from deforestation (as in Bajželj et al. 2014). C) Emissions under a Greenpeace vision for the food system, including reductions from 50% reduction in meat and dairy production and consumption, plus avoided deforestation and soil carbon sequestration (as in Bajželj et al. 2014; Smith et al., 2014; and Röös et al., 2017).

A 50% reduction in meat and dairy production by 2050 relative to current levels will result in reducing GHG emissions from the agriculture sector by 64% compared to projected emissions under the 2050 baseline trajectories (see Figure 2, based on data for an ecological livestock and healthy diet model from Röös et al. (2017)).

The reduction in emissions between the baseline scenario and the Greenpeace goal will be of 7 billion tonnes of CO_2e per year by 2050. This reduction in GHG emissions can be compared to the global limit of emissions for *all sectors* needed for avoiding dangerous climate change, which will be about 20 billion tonnes CO_2e per year in 2050, 10 billion tonnes CO_2e per year in 2070 and reaching 0 billion tonnes CO_2e per year by 2080 (Rogelj et al., 2016).

Under the Greenpeace 50% reduction target for meat and dairy, agriculture emissions could be reduced to 4 Gt CO_2e per year, creating a much more optimistic and feasible scenario for other sectors and for society to limit climate warming to levels that are within safe zones for humanity and biodiversity.

Montbéliarde cattle at an ecological dairy farm in France

Emissions under the Greenpeace vision for the food system

The ecological livestock model offers large opportunities for reducing climate emissions directly from reducing the number of animals and feed. These reductions could be further enhanced by carbon sequestration in soils and biomass on the land potentially freed from the 50% reduction of current animal production (croplands and grasslands not longer needed for feed production and for fodder or pasture, respectively).

In addition, reducing meat demand will reduce pressure on forested land, and potentially reduce emissions from deforestation. Deforestation emissions[2] can be significant: models estimate that emissions from changes in land-use linked to agriculture can reach approximately 7 billion tonnes of CO_2e per year in the

2. Deforestation can result in carbon that has been stored in the plant material and soil to be released into the atmosphere.

baseline scenario, mostly from sub-Saharan Africa and Southeast Asia (Bajželj et al., 2014). There is currently no estimation of how much of the deforestation emissions would be potentially avoided specifically by the 50% reduction in meat and dairy production towards 2050. However, livestock is a major driver of land-use change and deforestation.

Details on the estimation of greenhouse gas emission

According to the various available models, emissions from agriculture under an ecological livestock system will range between 4 and 11 billion tonnes of CO_2e per year in 2050, while baseline emissions will range between 11 and 15 billion tonnes of CO_2e per year in 2050 (see Box 2, Table 1, Figure 3).

Including land-use change considerations will add more than 5 billion tonnes CO_2e per year to those estimations, with baseline emissions of agriculture including land-use change reaching up to 20 billion tonnes CO_2e per year. This range of values is based on a number of scientific models available reviewed in this report (see Table 1 and Figure 3 below).

Assuming that technological innovation and improvements in efficiency will make it possible to minimise GHG emissions in the livestock sector with ecological methods by 2050, we conclude that an ecological livestock system with 50% reduced meat and dairy production and consumption by 2050 will achieve a reduction of 64% of food related GHG emissions relative to BAU: 4 vs 11 billion tonnes of CO_2e per year in the baseline (BAU), based on data from Röös et al., 2017, see Figure 1. See Box 2 on scientific models for more details.

The reduction in emissions between the baseline scenario and the Greenpeace goal of 50% reduction and ecological production model will be of 7 billion tonnes of CO_2e per year in 2050 (11 Gt CO_2e yr^{-1} vs 4 Gt CO_2e yr^{-1} as per Röös et al., 2017). This amount of reduction in GHG emissions can be compared to the global limit of emissions for all sectors needed for keeping the planet below 1.5°C, which will be about 20 billion tonnes of CO_2e per year in 2050, 10 billion tonnes of CO_2e per year in 2070 and reaching 0 billion tonnes of CO_2e per year by 2080 (Rogelj et al., 2016).

These reductions in GHG emissions come from reductions in the number of animals that need to be kept and their corresponding emissions, and reductions in the emissions from feed production (e.g. emissions from fertiliser applications as nitrous oxide from soil, methane from ruminants and emission from manure management). The estimations presented in Figure 3 do not include land-use change emissions specifically.

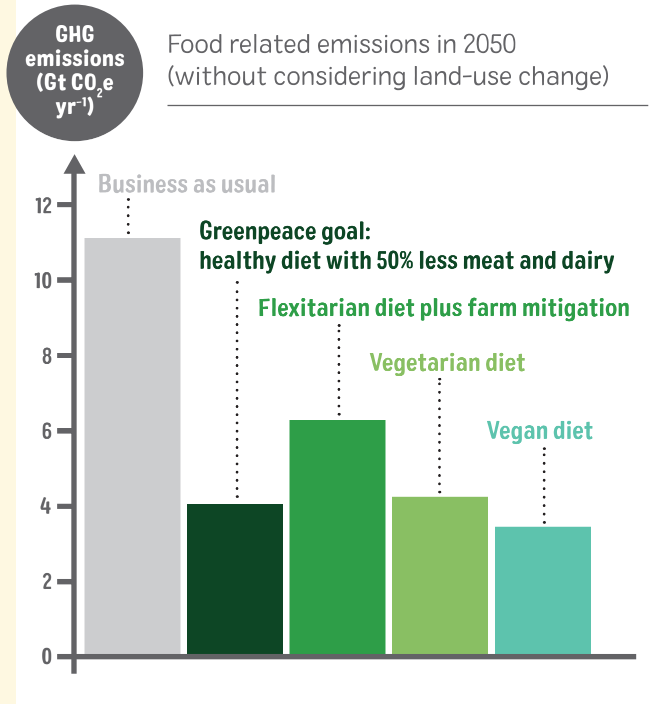


Figure 3. Food-related greenhouse gas emissions in 2050 under different scenarios: Business as Usual, baseline scenario as in Röös et al. (2017) (grey bar); Greenpeace goal, 50% reduction of meat and dairy production and consumption in 2050, as estimated in Röös et al. (2017) (dark green bar); flexitarian diet with reduced meat consumption (75% of animal food is replaced by pulses and cereals on kcal basis), increased productivity and technical mitigation in farming, as in Hedenus et al. (2014) (middle green bar); vegetarian diet, as in Springmann et al. (2016a) (light green bar); and vegan diet, as in Springmann et al. (2016a) (blue bar). Absolute values should be compared with caution because they are taken from different models that employ different methodologies and assumptions. Values for the baseline scenario range from 11 to 15 Gt CO2e yr^{-1} in different models (Bajželj et al., 2014; Hedenus et al., 2014; Tilman & Clark, 2014; Schader et al., 2015; Röös et al., 2017; Springmann et al., 2016a), see Table 1.

Particularly, GHG emissions from the ecological livestock model from Röös et al. (2017) do not include potential savings in emissions from land that is released through dietary change and that could be potentially used to sequester carbon through reforestation and afforestation or used for nature conservation (Röös et al., 2017). These carbon sequestration gains can be significant, but are also uncertain and hard to quantify (e.g. they are time limited due to saturation of carbon in soils and biomass, reversible, and associated with economic and social complexities).

Note on the estimation of greenhouse gas emissions relative to 1.5 °C targets under the Paris Agreement

Comparing emissions under the Greenpeace vision for the food system in 2050 to the Paris Agreement emission scenario for a 2050 with a warming limited to 1.5 °C,

Box 2: Scientific models

A number of scientific models have recently estimated GHG emissions under agriculture production scenarios aimed at minimising environmental impacts, while providing enough food for humans. Here, we broadly compare the most relevant ones relative to Greenpeace's vision for reducing meat and dairy by 50% in 2050.

In order to estimate future scenarios, these models calculate the agricultural land that would be available to feed animals after taking care of human food and biodiversity conservation. Then, the models estimate how much meat could be produced with the agricultural land not required for human food or biodiversity. In particular, they calculate how much ruminant livestock and dairy could be produced on grasslands (taking into account biodiversity conservation) and how much pork and/or poultry could be fed from food waste and crop residues, with minimal feed crops. These models provide an approximation of the possible amount of livestock production to minimise environmental impacts and ensure food security.

The estimates in these models do include a degree of uncertainty, as different models have different assumptions and methodologies, therefore making it difficult to compare results among them. However, these models are extremely useful in giving us information about the ranges of outcomes that could be expected from reducing meat and dairy production and consumption, in particular the potential GHG emissions savings from different models.

Table 1 shows the range of values found from scientific models estimating food-related GHG emissions in 2050. The disparity in estimations can be explained by differences in the model assumptions, parameters and methodology. We consider the Röös et al., 2017 model to be the one that closest represents the ecological livestock system in Greenpeace's vision, and thus we single out this estimation, with ranges illustrating variations with other models (Table 1).

The Röös et al. (2017) ecological livestock model includes reduction in meat and dairy production plus the implementation of a healthy diet globally. Such a healthy diet is based on a composite of recommendations from the World Health Organisation, Harvard Medical School and American Heart Association (with a cap at 2500 kcal/person/day in all regions). Yields and food waste levels were maintained at current levels for the 2050 modeling results we are reporting here.

	Food-related GHG emissions in 2050 (billion tonnes of CO2e per year)			
	Baseline	ECO	VGT	VEGAN
Röös et al., 2017	**11.0**	**4.0**		**3.0**
Schader et al., 2015	14.0	11.3		
Springmann et al., 2016a	11.4		4.2	3.4
Hedenus et al., 2014	12.0	6.8		
Tilman and Clark 2014 (w/ LUC)	15.0		6.5	
Bajzelj et al., 2014 (w/ LUC)	20.2	9.3		

Table 1. Summary table with different scientific models estimating GHG emissions under reduced meat and dairy consumption. Baseline: Business as Usual scenario. ECO: Greenpeace goal with an ecological livestock system and 50% reduction of meat and dairy production and consumption by 2050, VGT: Vegetarian diet, VEGAN: Vegan diet. Only Bajzelj et al. (2014) and Tilman & Clark (2014) include land-use change (LUC) in their estimations.

includes a high level of uncertainty. We include here only an approximation as more precise modelling would be required. Such modelling would require the complex integration of all different sectors for a world vision for 2030, 2050 and beyond including considerable long-term data. However, in spite of this uncertainty, it is possible to make useful approximations that estimate current and future emissions under the 50% meat and dairy reduction target and compare them to global GHG emission budgets for 1.5 °C targets.

In very simplistic terms, to keep the global temperature increase below 1.5 °C, as per the Paris Agreement, global GHG emissions including all sectors (e.g. energy, transport, industry, food, etc.) must not exceed 30 billion tonnes of CO_2e per year in 2030, with a lower limit of 20 billion tonnes of CO_2e per year in 2050, 10 billion tonnes of CO_2e per year in 2070 and reaching zero net emissions by 2080 (Bajzeli et al., 2014; Rogelj et al., 2016).

As highlighted above, direct agriculture emissions under the reference baseline in 2050 could range between 11 and 15 billion tonnes of CO_2e per year (reaching 20 billion tonnes of CO_2e per year in 2050 when including land use change), thus exhausting the global GHG emission budget for all sectors by itself.

Beef and pork on sale in a German supermarket

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How much meat and dairy is a 50% reduction by 2050?

Greenpeace's vision of an ecological food system with 50% less meat and dairy delivers a reduction of 50% from current levels of livestock production. This reduction can be translated into how much meat and dairy will be available per capita in 2050 compared to today, and to what is projected to be the global average in 2050.

The vision estimates a global meat production of 155 million tonnes per year by 2050, compared to a projection of 455 million tonnes per year in the baseline scenario estimated by the FAO for the same year (Alexandratos & Bruinsma 2012; FAOSTAT, 2018).

Current production is 310 million tonnes per year of meat worldwide (latest data from FAOSTAT is year 2013, as of January 2018). The Greenpeace goal translates into a reduction of 50% from current levels of livestock production and a 66% reduction relative to BAU in 2050 (FAO) (Figure 4).

As mentioned above, this reduction target is in line with what many scientific analyses consider to be the ecological level that the Earth system can sustain while achieving food security and a safe climate and biodiversity.

According to another analysis, 70% of the current livestock production represents an inefficient use of land, both for grazing livestock and animal-feed production (Bajzeli et al., 2014). These scientists concluded that only 30% of *current* livestock production would be a sustainable and efficient use of the land. Greenpeace estimates a rather optimistic view on what level of meat production could be achieved sustainably *in the future*, by 2050, 155 million tonnes or 50% of what the world produces today. The Greenpeace target value is slightly more optimistic because it leaves room for improving future productivity in some regions with ecological farming, and also includes increased use of crop residues and wasted food as animal feed (while reducing food waste values in absolute terms), as estimated in scientific models (Hedenus et al., 2014; Schader et al., 2015; Röös et al., 2017) .

Greenpeace's goal in terms of global livestock production can be translated into how much meat and dairy will be available per capita in 2050 compared to today and to what is projected to be the global average in 2050.

The latest United Nation projection estimates a human population of 9.8 billion people in 2050. Considering the targeted meat production under Greenpeace's goal (155

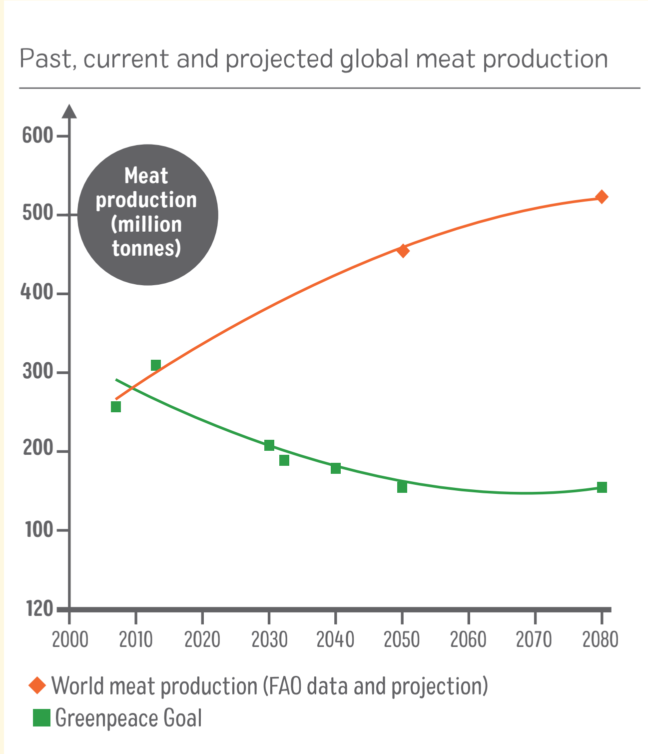


Figure 4. Past, current and projected global meat production, as projected by the Food and Agriculture Organisation of the United Nations under the reference baseline (Business as Usual) scenario (red line) compared to the progression towards the Greenpeace goal of ecological livestock with a 50% reduction in meat and dairy production and consumption by 2050 (green line). Source: Alexandratos & Bruinsma (2012) and own estimations using FAOSTAT 2018 data.

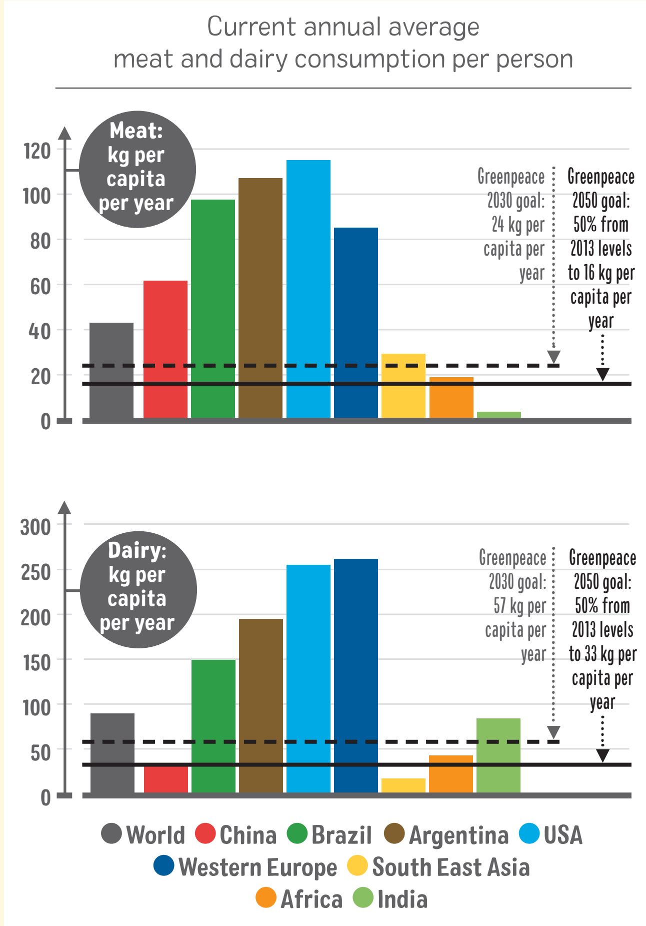


Figure 5. Current global average meat and dairy consumption and in China, Brazil, Argentina, USA, Western Europe, Southeast Asia, Africa and India (data for year 2013, the latest current data available from FAOSTAT, 2018). The red line shows the Greenpeace goal for reduced consumption by 2050 and the green line shows midterm goal by 2030. Kg of meat refers to carcass weight, meaning raw unprocessed products at the point of retail sale, as defined by FAOSTAT.

million tonnes) distributed equally across regions, it results in an estimated global consumption of 16 kg per capita per year.[1] That relates to approximately 300 g per capita per week of all meat products (in carcass weight, meaning raw unprocessed products at the point of retail sale). Similarly, for dairy, the 50% reduction results in an estimated global consumption of dairy of 33 kg per capita per year in 2050, which results in 630 g per capita per week (a glass of milk is roughly 200 g).

This reduction corresponds to the recommended weekly amount by the World Cancer Research Fund for a healthy diet of a maximum weekly amount of 300 g of red meat. The health implications of meat and dairy consumption are explained further in Chapter 3.

In the year 2030, if we consider a gradual decrease of meat consumption, the estimated consumption would translate into 24 kg per capita per year, compared to a current global average of 43 kg per capita per year, and of 85 kg per capita per year in Western Europe. For dairy in 2030, the target will be at 57 kg of dairy per capita per year. This will allow some room for increases in China, Southeast Asia and Africa towards 2030; all other regions will have to decrease their average dairy consumption significantly (see Figure 5).

Reducing production of meat and dairy will naturally lead to a focus on the demand for livestock products. Bajzeli et al. (2014) state the need for demand-side reductions relative to mitigation potential from agriculture and land use: *"Only when strategies include significant elements of demand reduction is it possible to prevent an increase in agricultural expansion and agriculture-related GHG emissions."* The authors continue: *"The livestock sector should be included into a comprehensive climate mitigation policy."*

1. Throughout this report, kg of meat refers to meat as 'carcass weight' as defined by FAO, it includes all types of meat, processed and unprocessed, and it refers to the quantity of uncooked meat supplied at retail level. Carcass weight of meat in kg refers to the parts of the animals after slaughter that are technically edible, that are supplied to consumers in a given country or region. Waste before reaching consumers is included, but not the waste in the home.

Regional considerations on equity and 'common but differentiated' responsibilities

Regional meat consumption trends for the past four decades show the sustained levels of very high meat consumption in the West (for example, the USA and Western Europe) and Argentina, compared to the global average and to developing areas (Brazil, China, India, and Southeast Asia and Africa as regions in Figure 6). Future projections indicate how different regions of the world are converging to similar patterns of high meat consumption and Westernised diets (Malik et al., 2012).

In China, meat consumption has increased significantly in the past 20 years, although previous to 1995, consumption was well below the world's average (Figure 6, data from FAOSTAT, 2018). Brazil's levels of meat consumption have been increasing steadily, currently surpassing levels in Western Europe. The Southeast Asia region has seen increases in meat consumption in the last decade, although averages are still below the world average values. India and countries in Africa have not seen important increases in the past decades, with averages still well below the world's averages (Figure 6).

The Greenpeace vision of ecological livestock would ensure a world without inequalities in access to resources, including access to a healthy and culturally appropriate diet. To achieve an equitable access to animal products, low-income societies would have access to increased consumption of animal products if desired.

"The Greenpeace vision of ecological livestock would ensure a world without inequalities in access to resources, including access to a healthy and culturally appropriate diet"

This is the 'shrink and share' approach that Greenpeace has advocated for since the publication of the Ecological Livestock report (Tirado & Kruszewska, 2012). However, this will mean drastic cuts in the consumption of animal protein in high meat-consuming parts of society (including affluent sections of society within middle- or low-income countries) and it will allow a moderate increase of consumption in less affluent parts of societies, following the shrink and share principle.

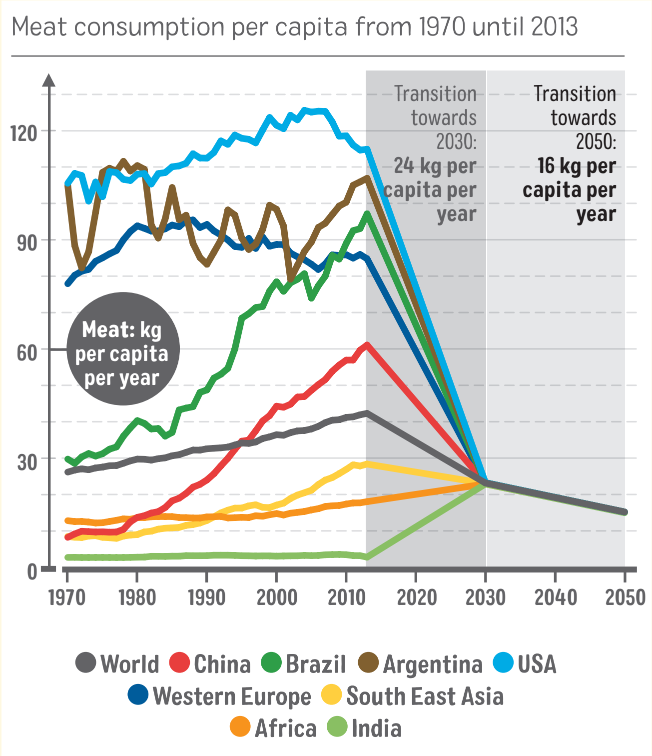


Figure 6. Average global meat consumption per person from 1980 to 2013, and in the USA, Argentina, Brazil, Western Europe, China, Southeast Asia, Africa and India (FAOSTAT, 2018, latest data for 2013, per kg of meat in carcass weight). We indicate the target values for the Greenpeace goal towards 2030 and 2050.

Achieving a balanced intake of animal protein among the poorer people in the world will inevitably require drastic cuts in the richer sections of societies, even in developing countries.

Regional estimations

If we assume a shrink and share approach to future animal products consumption in which all regions converge towards a global average, this transition could allow for a moderate increase in consumption in the lower meat-consuming regions of the world (e.g. India, Africa towards 2030, then gradual decreasing towards 2050). High meat-consuming regions will have to decrease average levels significantly first to 2030 and then towards 2050 (see an approximation visualised in Figure 6). Naturally, the size of the reduction needed will be larger in the regions with the highest consumption. However, different regions have increased meat consumption at different rates in the last four decades (Figure 6). Where the increase in consumption has been very recent (for example, China and Brazil), the call for a drastic reduction in per capita consumption can be seen as not equitable compared to regions that have experienced sustained meat consumption for decades (for example, Western Europe and the USA).

A child eating an ecologically sourced lunch at kindergarten in Tokyo, Japan

Current and potential meat consumption per capita in 2050,

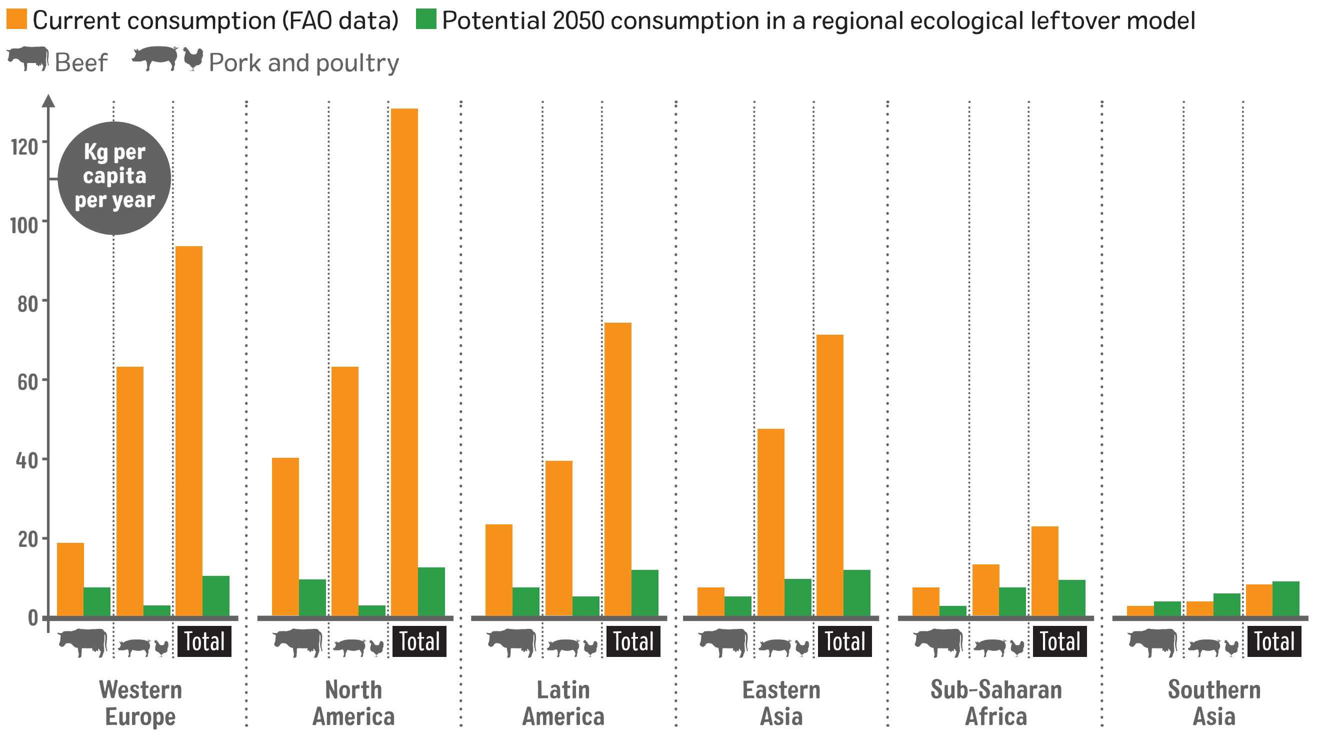


Figure 7. Results in Figure 7 are just a 'what if' illustration of the future, and not a Greenpeace vision or differentiated regional campaign target. Current and potential meat consumption per capita in 2050, under a region-specific model in which beef is only produced from regionally available grasslands and pork/poultry is produced only with feed from regionally wasted food and crop residues. These data are based on a regionally specific ecological leftover model developed by Röös et al. (2017) and current consumption by region from FAOSTAT (2018). Data from Röös et al. (2017) are presented in the red bars are not directly comparable to other Figures in this report, as they are kg calculated back from estimated available calories. The regionally specific ecological leftover model by Röös et al. (2017) is similar to the global Greenpeace model of 50% reduction of meat and dairy by 2050, but Röös et al. (2017) calculate potential consumption based only on available grasslands and food waste, without considering trade or potential future innovations in feed production. The values in this figure represent a more limiting estimate of how much beef and poultry/pork could be consumed in 2050 regionally, compared to the global projected average estimated annual consumption of 16 kg meat per person per year. Target values would need to be revised when more advanced models become available.

"As far back as 1992, the United Nations Framework Convention on Climate Change (UNFCCC) committed to the principle of 'common but differentiated responsibilities', in which countries have a common responsibility in reducing GHG emissions, but historic emissions and differences in current development levels mean that countries have different levels of emissions reduction obligation." (Althor et al., 2016).

Clearly, integrating this principle into the climate negotiations has proved difficult. Further, operationalizing this principle of 'common but differentiated responsibilities' among different countries when addressing the regional implications of global meat and dairy reduction targets will be highly complex. Considerations about regional historical trends and equity have not been taken into account in this report, due to limitations in scope and current gap in detailed scientific analysis on this matter.

Current and future levels of meat consumption are shaped by the production capacity of the land available in any given region, plus other important factors like culture, traditions, social and ethical dimensions that impact the quantity consumed in different countries.

The regional projections of the Greenpeace global goal are based on the study by Röös et al. (2017). The study provides an approximation of the regional levels of animal product consumption that would be feasible under the assumption of an ecological livestock model (ruminants produced on available grasslands, use of animal feed restricted to crop residues and wasted food, while human food waste reduced 50% compared to today's levels). This model, however, does not include the regional influence of any other factors beyond production capacity of the land, like culture and traditions, equity across regions, or any other social or ethical dimension.

Figure 7, left shows data from Röös et al. (2017) for different global regions. The figure illustrates the extent of changes needed to happen from current consumption patterns to a region-specific 2050 model based *only* on land availability.

This model considers a larger population in 2050, a 50% reduction in food waste, and limitations on land available in each region for beef (only produced from grasslands) and pork (only produced from wasted food and crop residues). This model does not include the production of poultry and eggs, because pork is considered as more efficient in feeding on food waste than poultry. For illustration purposes, Figure 7 includes both pork and poultry: one or the other could be chosen as a prefered regional option of meat produced from food waste.

Results from this model in Figure 7 represent only the production capacity of the land, without any potential improvements, economic developments or trade (Röös et al. 2017). This is a simulation to illustrate 'what if' scenarios per each region, without considering trade, and does not imply that the future will look like this. **Results in Figure 7 are just a 'what if' illustration of the future, and not a Greenpeace vision or differentiated regional campaign target.**

In some cases, this analysis results in lower meat availability per capita in each region than the global estimation of 16 kg per person per year given as result of the Greenpeace goal (Figures 5 and 6). For example, in sub-Saharan Africa crop production capacity will remain low in 2050, and thus meat production potential from only regional grasslands and food waste will be very low. Meat consumption in sub-Saharan Africa in 2050 under this model looks lower than today's levels, which are very low meat consumption averages and where malnutrition is extended.

It must be noted that currently, the prevalence of malnutrition is the result of inequality in the distribution of resources within and across countries, including inequality in the access to food and to animal products, highlighting the complex issue of historical meat consumption and reduction targets in different regions.

To our knowledge, the need to consider food-related inequality and past historical trends with regards to region-specific future meat reduction targets has not been addressed scientifically or in previous models. There is an urgent need to develop models that incorporate scenarios where, for example, high-income societies with previous long-term meat consumption drastically reduce consumption, so that other societies could maintain or even slightly increase consumption. These scenarios are highly complex as they must consider many factors beyond land use and agriculture productivity, like culture, tradition, human health, societal development and innovation potential. We look forward to a comprehensive analysis on food justice and equality of diets to be developed in the near future, so they can be incorporated into the Greenpeace vision of an ecological food system with equality across regions and societies.

With regards to future diets and availability of resources for food, it has been indicated that South Asia and sub-Saharan Africa are the regions where the pressure to expand agricultural land will be more intense, due to pressures from increasing demand of agricultural products regionally (Bajzeli et al., 2014). These are also regions where historical and future conflict between domestic demand and exports seem to be more likely, and where special attention should be given to the achievement of sustainable diets for human health, and protection of natural resources and land for biodiversity conservation needs.

Climate friendly future

This chapter outlines how a more equitable shared-responsibility future for food security, with climate responsibility, can be achieved if Western regions and the most affluent sections of societies globally take the lead in moving towards more plant-rich diets.

In addition to climate considerations, the ethical, social, economic, environmental and health pressures resulting from the high consumption of animal products should be equitably shared among different regions of the world and among different sections of our societies.

The importance of low-impact livestock production systems in rural areas should also be taken into account within this future framework. The adoption of low-meat, plant-rich diets in urban and high-income sections of societies must not translate into an added burden for rural pastoralists and low-impact livestock systems in developing countries. There are options to minimise the climate impacts of low-impact livestock production systems (Herrero et al., 2016). We must find ways to ensure fair rural livelihoods and just economic transitions for livestock producers, particularly in developing regions. At the same time, the environmental, social and animal welfare impacts of any livestock system should be minimised.

The following chapter outlines in greater detail the environmental impacts of meat and dairy production, outlining the urgency to move towards a plant-rich diet to help limit climate change and stem the massive destruction of our ecosystems.

chapter two

Environmental impacts of meat and dairy

Introduction: The planetary boundary framework

In 2009, Rockström and colleagues pioneered a new approach for identifying and quantifying planetary boundaries which, if transgressed, could cause environmental change that may have disastrous consequences for humanity (Rockström et al., 2009). Their approach is seen by many as a practical way to guide human activities now and in the future (Steffen et al., 2015). The authors assess nine planetary systems that are vital for human existence and aim to quantify the current position in 'operating space' within them – from healthy to beyond safe limits.

Steffen et al. (2015) reported that the status of at least four planetary boundaries are beyond the zone of uncertainty (and currently in a high-risk state), or within increasing risk given the impact of current human activities on Earth. Biosphere integrity (biodiversity) and biochemical flows (particularly nitrogen and phosphorus) are known to have been exceeded and both land-system change and climate change are thought to be currently within the zone of uncertainty (with increasing risk). Further, there is some debate as to whether the freshwater use planetary boundary has been exceeded (Gerten et al., 2015; Jaramillo & Destouni, 2015).

One of the most significant human activities to impact on global biodiversity is agriculture. Campbell et al. (2017) examine the contribution that agriculture (not specifically livestock and dairy production) has in destabilising planetary boundaries. The impact of agriculture on the environment is well documented but complex in that it involved multiple pathways that interact simultaneously – for example, biodiversity requires land resources to exist.

According to Joppa et al. (2016) species extinction rates are currently estimated to be 1,000 times the background rate. Habitat loss and degradation are thought to be implicated as the most frequent drivers of the decline in terrestrial mammal and birds, and may be for other organisms not analysed in this particular study (Joppa et al., 2016).

Barnosky et al. (2011) suggest that habitat fragmentation, as a result of agriculture, may be contributing to one sixth of all species losses globally. Such species losses across all biomes on Earth suggest that a sixth mass extinction is now under way (Barnosky et al., 2011). In 2010, 5.1 billion hectares were required for global food production (Wirsenius et al., 2010). According to Westhoek et al. (2011), meat production was thought to be responsible for 30% of all biodiversity loss in Europe in 2011.

Animal feed is a significant factor in the environmental impact of meat and dairy production. Globally, approximately 75–80% of all agricultural land is used to produce fodder for livestock (Foley et al. (2011) report 75%, Stoll-Kleemann & O'Riordan (2015) report 80%).

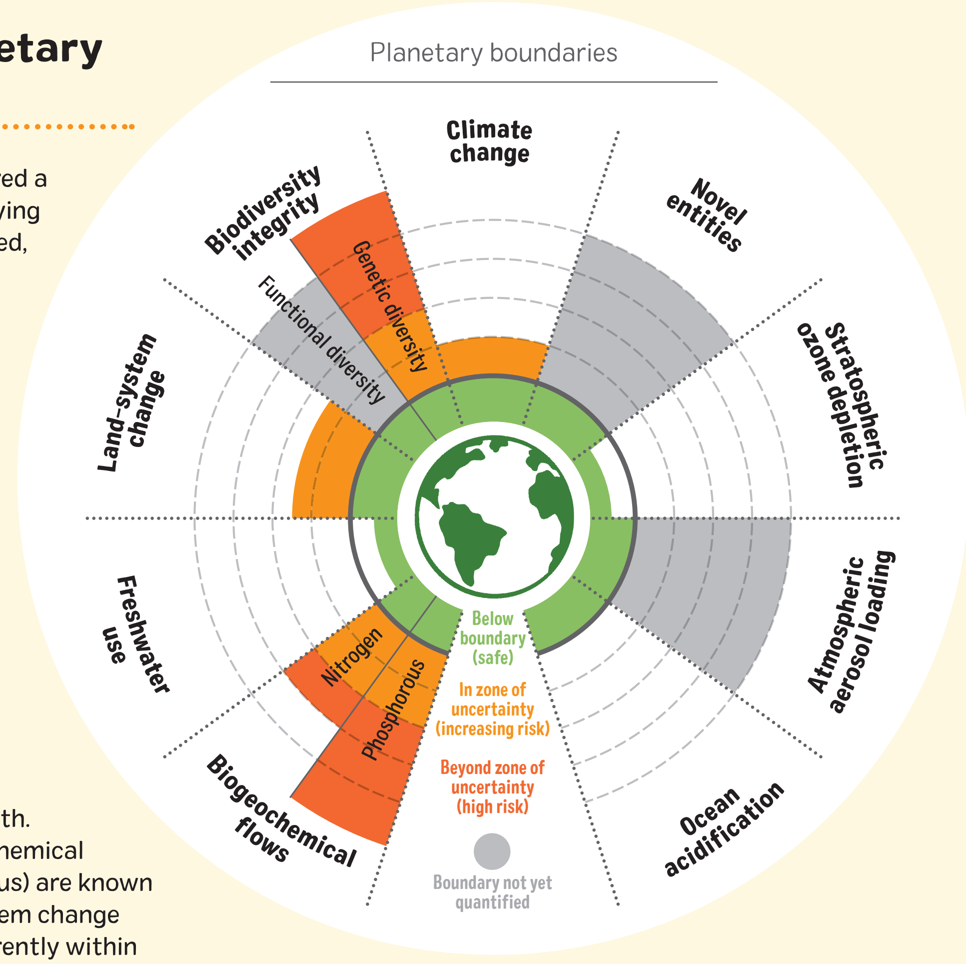
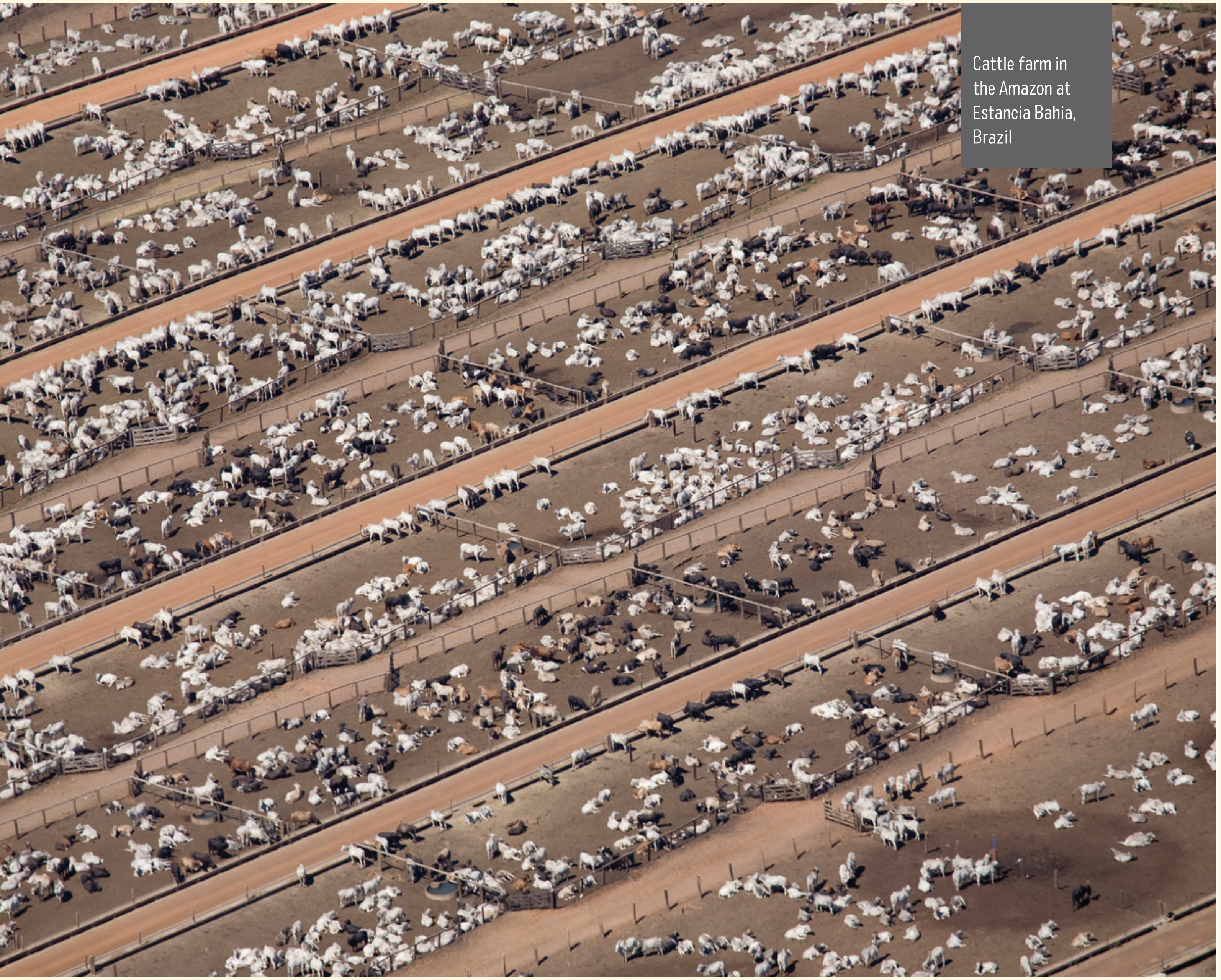


Figure 8. Planetary boundaries: Key factors that ensure a habitable planet for humans. Of nine worldwide processes that underpin life on Earth, four have exceeded 'safe' levels – human-driven climate change, loss of biosphere integrity, land-system change and the high level of phosphorus and nitrogen flowing into the oceans due to fertiliser use. Pollution with nitrogen and phosphorus fertilisers, together with biosphere integrity (biodiversity), are the two planetary boundaries under the high-risk zone for disruption of life on Earth. The 'novel entities' boundary refers to, "new substances, new forms of existing substances, and modified life forms that have the potential for unwanted geophysical and/or biological effects" (for example, microplastics, nanoparticles or genetically engineered organisms). From Steffen et al. (2015). Planetary boundaries: Guiding human development on a changing planet. Science, 347: 6223. Graphic © theguardian.com (2015).



Cattle farm in the Amazon at Estancia Bahia, Brazil

Some assessments suggest that 40% of grain and 80% of soy harvests are being allocated to feed animals for human consumption (Stoll-Kleemann & O'Riordan 2015). The consumption of animal products by humans has been described as the principle driver for wide-ranging global environmental impacts including land degradation, pollution, desertification, climate change, overfishing, coastal sedimentation, invasive species and the loss of wild carnivores and herbivores (Steinfeld, 2006; Ripple et al., 2014a; 2015).

Half of all global meat production takes place in developing countries, many of which are in tropical areas with particularly high levels of biological diversity or species richness (Machovina et al., 2015). However, per capita consumption of meat in developing countries is currently much lower when compared to developed countries, but with increasing trends globally (see Chapter 1).

Livestock production in many developing regions of the world, where agriculture is still a vital element in rural subsistence, can play a key part in the lives of many people, providing food, income, fertiliser, employment and security. Different livestock production systems, such as pastoral/agropastoral, mixed extensive, mixed intensive and industrialised systems, have very different patterns of resource use and resultant trade-offs. This review largely focuses on large-scale intensive, industrial meat and dairy production systems that are having a large negative impact on Earth's ecosystems.

Livestock are also known to be valuable assets within ecological farming, particularly smallholder farms. Cattle provide milk, ploughing power and manure with which to maintain soil fertility. Livestock are also key in helping smallholders spread financial risk throughout times when crop yields are diminished.

Land-system change: Current meat and dairy production and the impact on global land use

Steffen et al. (2015) aim to quantify land-system change to assess to what degree the safe operating zone has been transgressed. By crossing the planetary boundaries, and transgressing defined thresholds or tipping points, the authors suggest that the risk of irreversible and abrupt environmental change increases. Steffen et al. (2015) define a global measure for land-system change as the area of forested land as a percentage of original or potential cover before any human-related impacts. In 2015, global land-system change was estimated at 62%, meaning that only 62% of forest cover remains (Steffen et al., 2015). All measures of land-system change were assessed as being within the critical zone of uncertainty suggesting that, if human activities do not change trends in habitat loss, the safe operating space for humanity will be transgressed (Steffen et al., 2015). Based on the findings of two studies from 2012 that use FAO data, Campbell et al. (2017) estimate that agriculture alone was responsible for 80% of land-system change transgression (Hosonuma et al., 2012; Kissinger et al., 2012).

Crop and pastures are one of the largest biomes on Earth. According to Foley et al. (2005), these agricultural areas cover approximately 40% of the planet's terrestrial surface. Forest gain has occurred in some northern latitudes and developed countries, though degradation is still ongoing in many developing countries (Sloan & Sayer, 2015).

Livestock production is the single most powerful driver of habitat loss on Earth (Machovina et al., 2015). Over the past 50 years, an average of 25 million domestic ruminants have been added to the planet every year (Ripple et al. 2015). Spatial modelling of the global distribution of livestock has revealed that different livestock species are kept at high densities in different areas of the world (Figure 9) (Robinson et al., 2014). This means that livestock will impact different regions in different ways depending on the species that is kept at the highest densities.

Global distributions of cattle, pigs and chickens.

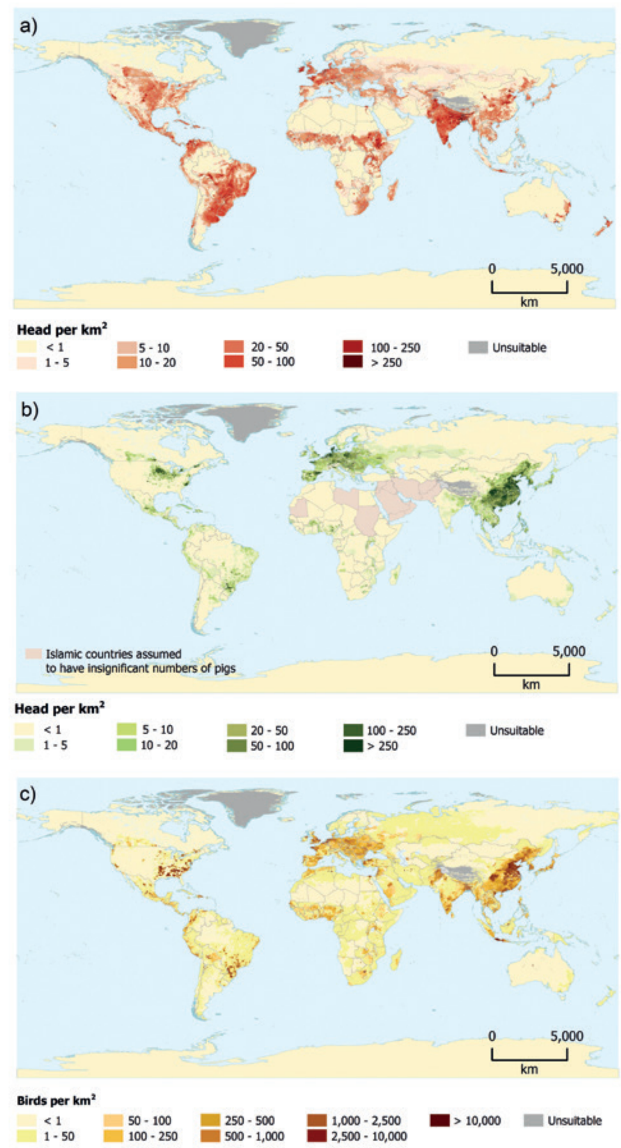


Figure 9. A summary of the global distributions of a) cattle, b) pigs, c) chickens. From: Robinson et al. (2014). Mapping the global distribution of livestock. PLoS ONE, 9: e96084. Distributed under a Creative Commons Attribution License 4.0 https://creativecommons.org/licenses/by/4.0.

Figures giving the total area of agricultural land used to feed livestock (grazing and grain) vary. Mottet et al. (2017) estimate that the land for both grazing and feedstock is approximately 2.5 billion hectares, which is around half of all global agricultural land. Almost 2 billion hectares of this was reported as land for grazing livestock (Mottet et al., 2017). However, in other analyses the land area required for livestock production (crop and pasture land) is estimated at approximately 75-80% of all agricultural land (Foley et al. (2011) report 75%; Stoll-Kleemann & O'Riordan (2015) report 80%). Ripple et al. (2014b) suggest that the land required to graze livestock equates to around 26% of the terrestrial surface of the planet. Land used for growing cereal feed for livestock is thought to be up to 210.5 million hectares (Ripple et al., 2014b). Both grazing and producing feedstock for domestic animals is in direct competition with producing crops for human consumption, climate mitigation and maintaining biodiversity.

The impact of extensive cattle grazing on carbon sequestration is complex. In some circumstances, well managed grazing can cause carbon to be sequestered into the soil. This is particularly true when cattle are grazed on rough ground that is not suitable for other uses, such as crop cultivation. Ruminants can fertilise these areas with manure. However, as soil carbon reaches an equilibrium, any initial benefits of cattle grazing will be outweighed after several decades, by the contribution that these livestock make to GHG emissions (Garnett et al., 2017).

Land use for different meats and production systems

Global beef production requires significantly more land than the production of other animal-based products. **According to Eshel et al. (2014) the land required for beef production is 28 times greater than dairy, pork, poultry and eggs combined. Beef requires a particularly high consumption of feed (grazing and feed) when compared to meat available for human consumption, such as poultry.** Even when excluding rough pasture resources, and therefore only considering prime agricultural land, beef still requires more land per kg than other meats. Figures describing the ratio of feed to food vary and range between 6 kg and 20 kg of grain per kg of beef (Garnett, 2009; Eshel et al., 2014; Mottet et al., 2017).

There has been a drive to increase the efficiency of the production of meat, dairy and fodder crops with the aim of reducing the need for more land. However, this intensification is accompanied by a greater use of fertilisers, pesticides and other external inputs that impact on biodiversity (Kastner et al., 2012). There is also the ethical and animal welfare aspect of whether intensification of animal production by creating extremely large facilities is acceptable, even if production efficiency is improved and, in some cases, harmful outputs are reduced. Concentrated animal feeding operations (CAFOs) are farms where over 1000 'animal units' are confined for over 45 days per year. The USA Department of Agriculture defines an animal unit as 'an animal equivalent of 1,000 pounds (~ 450 kg) live weight and, therefore, 1000 units equates to around 1,000 head of beef cattle, 700 dairy cows, 2500 pigs weighing more than 250 kg each, 125,000 broiler chickens or 82,000 laying hens. Manure from these facilities can be treated and in some cases recycled, but animals are often treated with many external inputs such as routine doses of antibiotics (see Section on antibiotic resistance).

Pork and poultry production may require less land area than global beef production due to the fact that a large proportion of production is highly intensified. Herrero & Thornton (2013) suggest that around 76–79% of pork and poultry production is industrialised with significant inputs, such as feed and veterinary medicines. Demand for these monogastric-derived meats is predicted to increase in future. Currently, intensive pork and poultry systems rely on grain- and soybean-based feed, which have considerable environmental footprints. Raising animals at such high densities also generates particular challenges to animal health due to stress and ease of disease transmission.

A life-cycle assessment carried out by Nguyen et al. (2012) estimated that **European pork production may cause damage to the environment that at the cost of around EUR 1.9 per kg** in terms of eutrophication, acidification, land use and GHGs. For the farmer raising these pigs, each kg costs an average of EUR 1.4. Most of the environmental costs for pork production stem from feed production, particularly the farming of soybean meal. The expansion of soybean production in areas of the world such as South America poses a significant threat to biodiversity and is a major driver of deforestation (zu Ermgassen et al., 2016). Feeding pigs from food waste (swill) has been presented as a more sustainable method of production (zu Ermgassen et al., 2016; Salemdeeb et al., 2017).

Intensive poultry production also requires significant external inputs that can carry negative environmental consequences. Prudêncio da Silva et al. (2014) carried out a life cycle analyses to assess the impact of four poultry production systems. The greatest impact was related to the feed given to the chickens – the more grain required, the larger the environmental impact. The most intensive poultry production systems were estimated to have the largest impact and the feed conversion ratio was estimated at 3.1 kg of feed per kilogram of live weight (Prudêncio da Silva et al., 2014).

The effect of globalisation on patterns of land use

Globalisation connects people and goods around the world, which means the impact of meat and dairy production is now not limited to the country of its consumption. By tracking global commodities and international trade flows, Yu et al. (2013) found that consumption in developed countries not only increases pressure on domestic land use, but also in regions that are geographically distant. For example, 33% of the land used to produce all commodities consumed in the USA is displaced from other countries. The land that is required for these products could be, for example, used to grow crops to feed animals, for textiles, to acquire minerals and forest products. For the EU, this figure is at least 50%, and in Japan 92% – which refers to how much of the land required to generate all of the goods consumed, that are from outside the country. South America is a particularly

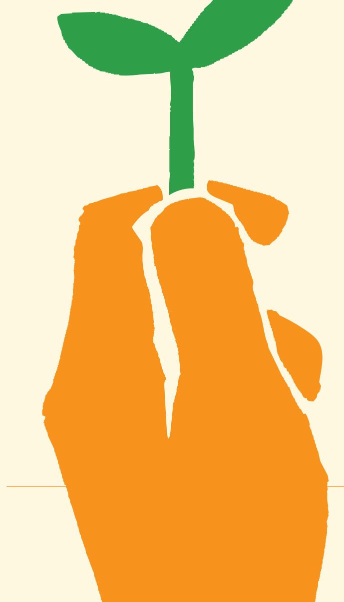
important area for cropland used for consumption in other areas of the word. In Brazil, 47% of all cropland is used for consumption elsewhere, and 88% of cropland in Argentina is used for both animal and human feed as well as other products, such as wood, textiles and minerals (Yu et al., 2013).

The expansion of grazing and cultivation of land on which to grow animal feed is often at the expense of native forest, grasslands or savannah (Stoll-Kleemann & Schmidt, 2017)**.** During the 50-year period from 1960 to 2011, the production of animal products was responsible for 65% of global land use change and the expansion in cultivated land (Alexander et al., 2015). The greatest change in land allocation was attributed to the supply of animal products to China during this period. This was thought to be primarily as a result of changing diets, rather than solely human population increases.

Growing feed and providing grazing for livestock requires clearing natural habitats. Much of the deforestation to make space for domestic livestock occurs in tropical regions, which typically have particularly high biodiversity. **In Amazonia, 80% of all deforested land has been converted to pasture for grazing animals, with much of the remaining 20% used to grow animal feed (Machovina & Feeley, 2014).**

Historically, initial deforestation of Amazonian rainforest was as a result of cattle production by smallholder practices that were followed by more intensive cattle ranching and soya monocultures (Pereira et al., 2016).

"Removal of natural forest, savannah and grasslands not only directly impacts biodiversity but also irreversibly changes entire ecosystems and global carbon cycling."



During a brief period (2006–2010) deforestation rates slowed as the soy industry expanded into land previously used for pasture production (Machovina & Feeley, 2014). However, rates have again increased and feed crop and pasture land is predicted to further expand. Eventually, all the remaining land outside protected areas will be at risk of clearance for soya production (Machovina & Feeley, 2014). In addition, an increasing demand for meat will mean that Amazonia is likely to come under further land-use pressure, given that much of the feed for livestock grown in Asia is imported from Brazil. In many countries (for example, China), increasing populations together with a shift to more meat-rich diets will further exacerbate land-use change.

Removal of natural forest, savannah and grasslands not only directly impacts biodiversity but also irreversibly changes entire ecosystems and global carbon cycling. Effective management of forests, pasture and cropland is essential for climate mitigation. Forests hold carbon within woody vegetation and soil, and deforestation can lead to significant carbon losses when the woodland is thinned, if some trees are chopped down, or removed entirely (Baccini et al., 2015). Tropical forests hold around 68% of global forest carbon stocks, above and below ground (Pan et al., 2011a; Bebber & Butt, 2017). Land-use change from deforestation and animal feed crop production is thought to contribute the largest proportion of CO_2 resulting from this type of agriculture. Steinfeld et al. (2006) estimated that such land-use changes were responsible for 2.4 Gigatonnes of CO_2 being released annually.

According to Guo & Gifford (2002), in addition to carbon loss due to deforestation and biomass loss, the conversion of forest to cropland has also reduced global soil carbon pools by approximately 40% over decadal time spans. The reduction in the ability of the soil to draw down CO_2 is due to the fact that organic matter is no longer returned to the soil and an increase in respiration of the soil after tillage (Arneth et al., 2017). Converting forest to grazing land has different effect on soils as soils in grazed areas are generally not tilled or perturbed in an intensive way, assuming that no heavy compaction of soils occur. Some studies have even suggested that grazing lands might have a greater ability to capture carbon in the soils (Guo & Gifford, 2002).

The composition of plant and animal species can be dramatically changed by the presence of grazing cattle (Kauffman et al., 1983; Read et al., 2011). Riparian systems (habitats around streams or wetlands) are particularly affected as cattle congregate in these areas to access water and lush forage. Livestock eat and damage vegetation making stream banks more unstable and vulnerable to erosion. This erosion can alter stream cover, water depth and width (Batchelor et al., 2015).

Biosphere integrity: The impact on biodiversity

The integrity of the land available for biodiversity is currently being compromised by the production of livestock. Land system change, freshwater use and imbalances in global biogeochemical flows will all influence biosphere integrity and the rate of biodiversity loss (Figure 10).

Biodiversity is often defined as the diversity of genes, traits, species, habitats and landscapes (Seddon et al., 2016). Evidence suggests that more biodiverse systems have greater intrinsic stability and resilience. Steffen et al. (2015) describe changes in biosphere integrity by describing the rate of biodiversity loss. These authors assess biodiversity loss by combining measures of genetic diversity (as quantified by extinction rates in extinctions per million species-years (E/MSY)) and functional diversity. The background rate of extinction loss, which is defined as naturally occurring extinctions in the absence of human actions, is thought to be 1 E/MSY. Steffen et al. (2015) assess current extinction rates to be much greater than the background rate and in the range 100–1000 E/MSY.

Widespread biodiversity loss

Global land-use change is associated with widespread biodiversity loss. There is a strong correlation between the intensity of agricultural land-use and the loss of species. A recent study of insect diversity and abundance, measured over 27 years in Germany, has suggested that a 76% decline in insects could be attributable to a number of changes in the environment including agricultural intensification (Hallmann et al., 2017). Agriculture has changed landscapes dramatically throughout the history of humans and this has altered the composition of species that can live within, and alongside, these human activities.

Much of the literature that describes the effects of livestock production on biodiversity concerns only a few taxonomic groups, specifically mammals and birds. These two groups are subject to more comprehensive assessments of threats through reviews conducted as part of the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. Habitat loss and degradation pose the most frequent direct threat to mammals and birds globally. According to Tilman et al. (2017), around **80% of all threatened terrestrial bird and mammal species are threatened by agriculturally driven habitat loss** (Figure 11). Other significant drivers of habitat destruction for terrestrial mammals and birds included logging, urbanisation and transport.

For both mammals and birds, the highest diversity of species is found in the tropics and these areas overlap with the greatest increases in human population growth between 1961 and 2010. Countries in tropical regions of South America, sub-Saharan Africa, Southeast Asia and China, with greater increases in per capita income and cropland within this period, had higher mean extinction risks for mammals and birds (Tilman et al., 2017). National extinction risks for these animals were positively correlated to the proportion of the country under cropland in 1961 and the subsequent growth in the extent of cropland and GDP per capita by 2010.

Examples of livestock production, particularly cattle grazing, directly interacting with wild species are numerous and date back several decades (Taylor, 1986; Knapp & Matthews, 1996). Livestock grazing has long

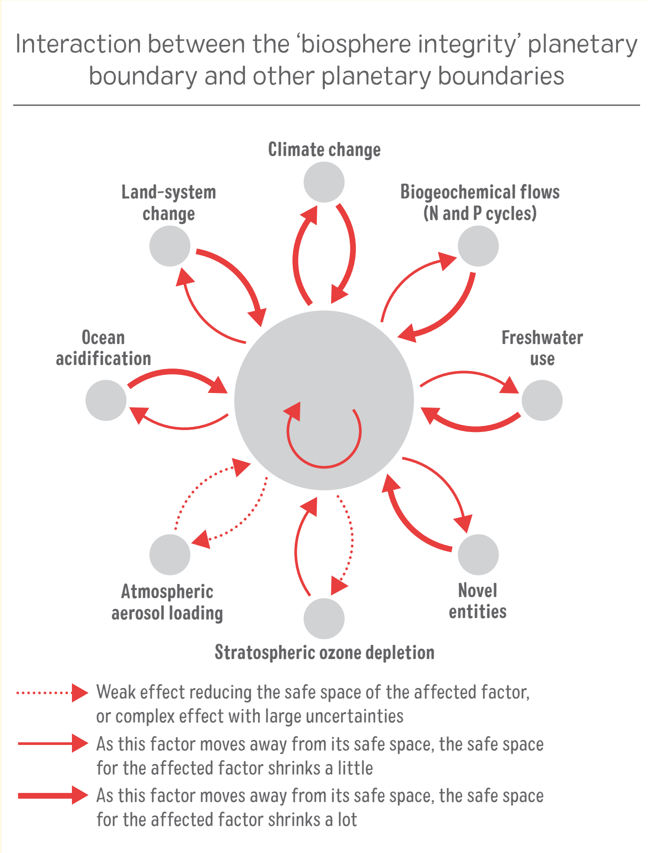


Figure 10. The interaction between the 'biosphere integrity' planetary boundary and other planetary boundaries. As a given factor moves further away from its safe space, the arrows indicate changes in another factor. Thicker arrows denote stronger and more closely related effects, whereas thinner arrows indicate weaker and less closely related effects. Dashed arrows indicate a weak and/or complex effect with large uncertainties. From Steffen, W., et al. 2015. Planetary boundaries: Guiding human development on a changing planet. Science, 348: 1259855. Reprinted with permission from AAAS.

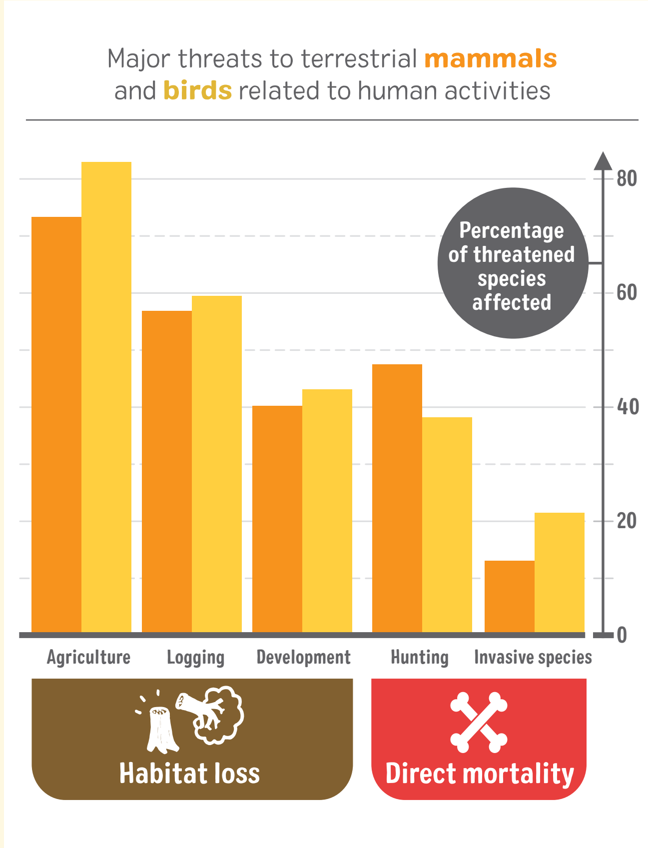


Figure 11. Major threats to terrestrial mammals and birds from human activities, according to the type of threat (habitat loss or direct mortality). Categories are aggregations of various stresses and threats, as defined by the International Union for Conservation of Nature. Reprinted with permission from Springer Nature. Tilman et al., 2017. Future threats to biodiversity and pathways to their prevention. Nature, 546: 73–81.

been known to lower population densities for a wide variety of taxa, disrupting nutrient cycling, altering freshwater systems and changing ecological community organisation (Fleischner, 1994). For example, 80% of the decline in vegetation in the Mongolian steppe has been attributed to overgrazing by livestock (Hilker et al., 2014). In a 10-year experimental study carried out by Evans et al. (2015), trophic interactions were monitored according to a number of livestock grazing treatments. Higher stocking densities led to changes in ecosystem dynamics across all trophic levels with significant effects on plant and arthropod (spider) densities, breeding bird territories, vole population cycles and the activity of a top predator (red fox).

Loss of top predators

Livestock production can also result in persecution (or deliberate killing) of wild predators. Large terrestrial carnivores are threatened on all continents in which they are found (Ripple et al., 2014a). Wild predators deliver considerable ecosystem services to humans through a number of direct and indirect pathways including carbon storage, the functioning of freshwater systems and crop production.

Large carnivores exert strong regulatory effects on ecosystems and their loss can mean that systems become unbalanced. Carnivores feed on other lower trophic levels and by doing so regulate ecosystems by maintaining a natural balance of richness and abundance in other species including other mammals, birds and invertebrates (Ripple et al., 2014a). The loss of carnivores is thought to be accompanied by changes in diversity of lower level predators, herbivores and plant species diversity. Vegetation changes will have wide-ranging influences on many other species. The largest of the terrestrial wild carnivores now occupy only 34% of the world's land area, in comparison to 96% in preindustrial times (Wolf & Ripple, 2017). Such a dramatic reduction in the global area across which wild carnivores roam is thought to be attributable to increasing densities of domesticated cattle and area of cropland. Prey depletion because of habitat loss is a major threat to large carnivores globally (Wolf & Ripple, 2016).

Wild predators that prey on livestock are also known to be subject to persecution in many parts of the world (van Eeden et al., 2017). The ranges of wild carnivores often overlap with areas of livestock production, particularly when wild prey become depleted. Predation on livestock by wild large carnivores has been estimated to contribute to up to 3% of local livestock holdings in areas of North America and Europe, and up to 18% in Africa and Asia (Thirgood et al., 2005). In areas where livestock are particularly important to the livelihoods of rural families, their loss to wild carnivores can be particularly devastating and result in retaliation.

Persecution on wild carnivores has already resulted in the extinction of two large-carnivore species; the Falkland wolf (*Dusicyon australis*) and the thylacine (*Thylacinus cynocephalus*). Currently, the threat of persecution from humans remains a serious threat to at least 85% of large terrestrial carnivore species (Suryawanshi et al., 2017). Some examples of carnivores that are perceived to threaten domestic livestock and as a result are the focus of human persecution include snow leopards (*Panthera uncia*) in the Himalayas, grey wolves (*Canis lupus*), lions (*Panthera leo*), leopards (*Panthera pardus*), striped hyaena (*Hyaena hyaena*), and the African wild dog (*Lycaon pictus*) in Africa (Thirgood et al., 2005). Managing wild prey populations could be a realistic way of reducing predation by wild carnivores on domestic livestock but only if accompanied by sufficient protection or deterrent measures, such as fencing, guard dogs or auditory deterrents (Eklund et al., 2017; Suryawanshi et al., 2017).

Threats faced by large herbivores globally

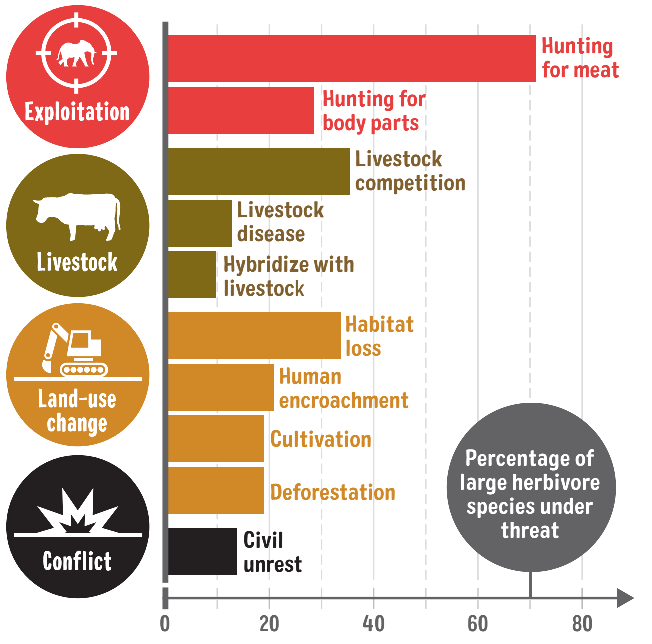


Figure 12. Threats faced by large herbivores globally. Threats faced by each species were categorized using information in the IUCN Red List species fact sheets. The total adds up to more than 100% because each large herbivore species may have more than one existing threat. From: Ripple et al. (2015). Collapse of the world 's largest herbivores. Science Advances, 1: 1–12. © The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. Distributed under a Creative Commons Attribution License 4.0 https://creativecommons.org/licenses/by/4.0.

Loss of large herbivores

Livestock production is a significant threat to large wild herbivores (body mass ≥ 100 kg) (Figure 12). Global livestock production tripled between 1980 and 2002, particularly in developing countries, encroaching on land used by wild grazers such as elephant, rhinoceros and giraffe species. The increase in livestock numbers has resulted in competition for grazing with a reduction in available foraging habitat and water for wild herbivores as well as greater risk of disease transmission (Mallon & Zhigang, 2009). According to Ripple et al. (2015), competition with livestock is threatening multiple species in Asia: India (seven species), China (seven species), Mongolia (four species).

Hybridisation with domestic species is also a significant threat. Examples of species where this is a particular issue include the Indian water buffalo (*Bubalus arnee*), Bactrian camel (*Camelus ferus*), wild yak (*Bos mutus*) and *Przewalski*'s horse (*Equus ferus*). Loss of these large herbivore species has significant implications for ecosystem functioning – elephants, for example, disperse seeds over large distances, hippopotamus maintain swamp channels and other grazers may maintain fire regimes (Ripple et al., 2015).

Interactions between livestock and wildlife can also result in novel disease transmissions. Wiethoelter et al. (2015) conducted a meta-analysis of publications investigating infectious diseases at the wildlife-domestic animal interface. The study included 15,988 publications dated between 1912 and 2013 showing an increasing trend, particularly at the cattle-wild artiodactyls (cattle-type animals) and bird-poultry interface.

Ensuring biodiversity resilience through mosaic habitats

The loss of native habitat is the principal driver of biodiversity loss. As continuous habitat is fragmented both genetic and demographic connectivity is eroded. Large scale monocultures can drive species losses as connectivity between fragments of native habitat is not possible for species that are not able to bridge the distances through dispersal.

Boesing et al. (2017) recorded long-term differences in bird species diversity in homogeneous monocultures on the Brazilian Atlantic coast (with a high proportion of cattle pastures) and mosaic/matrix coffee plantations that still retained some native habitat. The authors found that matrix habitats retained the diversity of bird species for longer and in farms where there was less than 20% native habitat, all diversity indices declined abruptly. In a similar study, Alvarado et al. (2017) investigated the diversity of dung beetle species under different livestock intensities in Mexico. The study found that forest cover (relating to landscape structure) was the best predictor of beetle species diversity and biomass. Maintaining forest fragments was essential for retaining beetle population in these livestock-dominated landscapes. To maintain biodiversity and prevent widespread extinctions across all species groups, retaining native habitats within agricultural landscapes is essential. However, mosaic landscapes should not be an intermediary step towards total deforestation and monoculture. Therefore practices, such as agroforestry, can ensure that sufficient agricultural yields can be maintained whilst promoting biodiversity and social equality (Oxfam, 2016).

Land-sharing versus land-sparing

Land is a finite resource and there will always be trade-offs among the various services and products it is used for. Achieving global food security and sovereignty while

Farmer Thoeun Huot herds his ecologically fed cows to new pastures in Kampong Chhnang province, Cambodia

ensuring protection of ecosystem services is the goal of an ecological food system. In some regions, this will mean increasing food production while *"recognising that agricultural yields are not always equivalent to food"* (Foley et al., 2011). Any increase in yields will have to be accompanied by ecological farming practices working with nature – combining farming with maintaining the provisioning of ecosystem services to improve the resilience and sustainability of land (see Foley et al. (2005)).

Scientists have been debating what could be the best approach for land use and protecting biodiversity whilst providing farming land that will feed almost 10 billion people by 2050. Two approaches are put forward, land sharing (with methods that integrate wildlife protection into sustainable farming) and land sparing (increasing agricultural efficiency by intensification and setting aside conservation areas for wildlife).

Land sharing or 'wildlife-friendly' farming aims to integrate food production and conservation within the same land area. This approach involves measures to maintain or enhance populations of wild species within areas of food production by modifying or restraining agricultural practice. Extensive grazing of cattle or sheep on permanent grassland, if managed correctly, could be considered a specific type of land sharing between livestock production and biodiversity conservation within an agricultural landscape.

A contrasting theory of land use is land sparing, which argues that intensive agriculture will lead to more land available elsewhere for conservation and biodiversity, for example forest protection. The land sparing approach is debated by some scientists and conservationists, as farmers aim to gain profits and not solely to feed themselves, and there is, in theory, no limit to demand for traded agriculture goods. If the profit per hectare increases, this could result in an extra incentive for agricultural expansion at the cost of deforestation and biodiversity loss. If profit per hectare declines, this could also be an incentive for deforestation, as more land is needed to make up the lost profit.

Swain et al. (2018) suggest that modern highly intensive livestock systems, particularly for beef, could offer a substantial reduction in land requirements and emissions per kg of meat. However, intensive cattle rearing schemes may require larger external inputs, such as chemical fertilisers and pesticides for feed production and medicinal treatments. There is also an ethical and animal welfare question as to whether animals should be kept in intensive conditions.

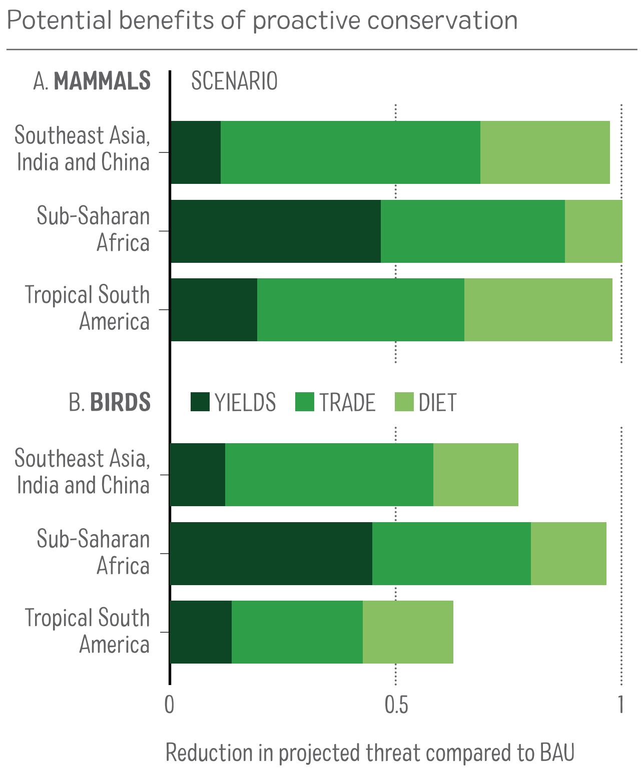


Figure 13. Potential benefits of proactive conservation compared to business as usual (BAU) scenarios for Southeast Asia, India and China (SAIC), sub-Saharan Africa and tropical South America. The estimated reductions in mean extinction risk values that would result from closing yield gaps (dark green), increasing conservation-based agricultural trade (medium green) and healthier diets (light green) for larger bodied mammals and birds. Each shaded portion of a horizontal bar shows the independent effects of each of the three proactive policies for a given region and species group. Reprinted with permission from Springer Nature. Tilman et al., 2017. Future threats to biodiversity and pathways to their prevention. Nature, 546: 73-81.

Ecological farming and livestock systems provide a balanced approach between the two theoretical, land sharing versus sparing extremes. Ecological farming aims to intensify ecosystem services and food production from the *same* piece of land. Theoretically the intensification of cattle could have positive impacts on biodiversity as less land is required for production. However, intensification can cause significant environmental costs that are often not accounted for in farming systems (Dorrough et al., 2007; Tscharntke et al., 2012). Agricultural intensification often does not account for the intrinsic complexity of biological/agricultural systems. In addition, the ecosystem services provided by rich biodiversity are often overlooked.

Tscharntke et al. (2012) conclude that, *"the true value of functional biodiversity on the farm is often inadequately acknowledged or understood, while conventional intensification tends to disrupt beneficial functions of biodiversity."*

Future agricultural practices will require balancing trade-offs between intensification and the resulting yield per unit area and the maintenance of biodiversity. The findings of Tscharntke et al. (2012) confirm the importance of biodiversity in sustaining agricultural yields. Ecological farming can include sustainable techniques that manage diversified habitats, avoiding pesticides and integrating soil fertility strategies that preserve functional biodiversity on the farm.

Proactive biodiversity conservation

"The safeguarding of biodiversity will require the expansion and more effective management of areas set aside to protect species, as many species lack adequate protection. New protected areas should be both sufficiently large and appropriately situated to optimize the protection of biodiversity while ensuring that countries can meet the food security and sovereignty needs of local people." (Tilman et al., 2017).

Besides ensuring habitat protection in conservation areas and with zero deforestation measures, Tilman et al. (2017) consider the potential benefits of proactive conservation and estimate the mean extinction risk in 2060 given better efficiency in agriculture, healthier diets with a 50% reduction in meat and increasing conservation-based agricultural trade. Most countries import between 5–15% of both human and animal foodstuffs. Tilman et al. (2017) propose a scenario where a further 20% of a countries' crop demands are met by countries with the highest yields. This scenario is what the authors suggest may be conservation-based agricultural trade as it predicts a reduction in both land clearance and extinction risks, in comparison with business as usual (BAU) scenarios. In general, Tilman et al. (2017) suggest that many nations currently have yields that are much less than their potential. Consequently, much greater sustainable yields could be achieved in future through practices, including planting legumes to increase soil fertility and the use of manure, cover crops and improved seed varieties.

Tilman et al. (2017) attempt to quantify two metrics of the extinction risks for mammal and bird species: the percentage of all species that are threatened with extinction in a country; and the mean extinction risk value for all of the species in a country. Increasing yields could reduce extinction risks by a range of 10–45% by 2060 (Figure 13). Changes in diet towards more plant-based food could reduce around 20–40% of the projected increase in extinction risk by 2060 for medium- and large-bodied species of birds and mammals, small-bodied species were also projected to benefit.

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An algal bloom in Dianchi Lake, China. Algal blooms can present problems for ecosystems and human society. Despite millions spent to clean up the lake, the water remains undrinkable and unfit for agricultural or industrial uses

Biogeochemical flows: Nitrogen and phosphorus pollution

Nitrogen is an indispensable nutrient for agricultural production. However, the threat posed by pollution as a result of intensification and inefficiency of production, both of livestock and feed crops, has a major impact on global ecosystems. According to Steffen et al. (2015), the addition of excess nitrogen and phosphorus to ecosystems in intensive, modern agricultural practices has greatly contributed to the transgression of the biochemical flow planetary boundary and the system is now outside a theoretical 'safe operating space'. The global average zone of uncertainty (or area beyond which will result in ecosystem instability) for that particular boundary is thought to be in the range of 11–100 Tg (a teragram is one million tonnes) per year for phosphorus and 62–82 Tg per year for nitrogen. The geographical distribution of these elements is critical in assessing impacts. Steffen et al. (2015) estimate that current values are ~22 Tg phosphorus per year and ~150 Tg nitrogen per year meaning that this zone is outside the safe operating space. This boundary exceedance impacts ecosystem functioning by redistributing important nutrients, particularly nitrogen and phosphorus, and contributing to widespread eutrophication of freshwater bodies, coastal regions and dead zones in the ocean (Crist et al., 2017).

Nutrients lost to the environment

Crop and livestock systems are responsible for the greatest alteration of global nitrogen and phosphorus cycles. According to Sutton et al. (2011) around half of the nitrogen used in agriculture is lost as aerosols or as runoff. Nitrogen that is added to soils will either be incorporated into the target crop or emitted to the environment through volatilization of gases, such as ammonia (NH_3), nitrogen oxides (NO_x), nitrous oxide (N_2O) and nitrogen gas (N_2), or through leaching and runoff of ammonium (NH_4), nitrate (NO_3^-), dissolved organic nitrogen (DON) and particulate organic nitrogen (PON). A recent study of the vadose zone (also known as the unsaturated zone that is between the surface of the land and the groundwater) estimated that this global area acts as a vast store of nitrates, which have previously not been fully accounted for in global nitrogen budgets (Ascott et al., 2017). Nitrogen travels through the vadose zone to surrounding groundwater, and therefore to coastal zones, at different rates in different global regions.

There are several ways in which livestock manure can emit NH_3, from animal housing and grazing, manure storage and during application of the manure to soils. N_2O can be emitted from agricultural soils either directly from the soil after the application of chemical fertilisers or manure, through crop residues or emissions from urine and manure. Indirect emissions of nitrogen also occur through leaching and runoff and volatilisation (Westhoek et al., 2014).

Some of the gases emitted through livestock production, particularly N_2O, are potent greenhouse gases and significantly contribute to climate change. Nitrous oxide (N_2O) has a global warming potential 265–298 times that of CO_2 for a 100-year timescale. N_2O emitted today remains in the atmosphere for more than 100 years, on average.

In addition to the nitrogen that is used and lost to the environment during livestock production, phosphorus is also an essential element in agriculture and a major pollutant of the aquatic environment. Both nitrogen and phosphorus are lost through manure and sewage. The total nitrogen and phosphorus generated by manure during livestock production exceeds global fertiliser use (Bouwman et al., 2009; 2013).

The use of phosphorus in farming is highly inefficient and only 4% of the phosphorus fertiliser and livestock supplements entering agriculture in the USA is fully transferred to products for human consumption, with the remaining 96% lost to surface waters, other parts of the food chain or exported (Metson et al., 2014). Phosphorus is required for all life in that it forms the backbone in the structure of DNA. It is a non-renewable global resource that is becoming increasingly scarce.

Relative contribution of each animal product to the overall environmental burden of phosphorus pollution in the USA

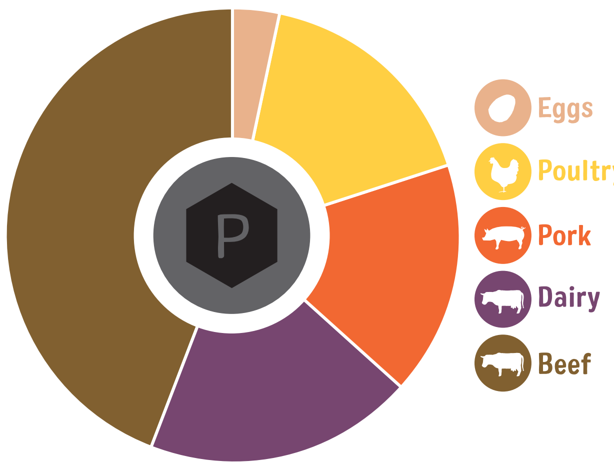


Figure 14. Relative contribution of each animal product to the overall environmental burden of phosphorus pollution in the United States. Figure adapted from Metson et al. (2014). Phosphorus is a key component of the resource for meat, eggs and dairy production in the USA. Proceedings of the National Academy of Sciences, 111: E4906–E4907. Reproduced with permission from PNAS.

Phosphorus is often a limiting nutrient in the aquatic environment. This means that the growth of certain organisms can depend on the presence of phosphorus and when this element is readily available, population increases can occur quickly. An example of this phenomenon is when pollution with excess phosphorus stimulates toxic algal blooms, resulting in a range of negative consequences.

Metson et al. (2014) describe a 2014 bloom in Lake Erie, which spans the USA and Canada, that resulted from excess phosphorus. The bloom affected human drinking water and deprived around 400,000 residents from potable supplies. According to Metson et al. (2012), animal product consumption accounts for 72% of the global phosphorus footprint. Beef and dairy production accounts for the largest proportion, around 60%, of this phosphorus footprint and the authors agree that decreasing the consumption of animal products would reduce environmental impacts (Figure 14).

Nitrogen excretion per kg of meat is also much less for poultry and pork than for beef. Bouwman et al. (2013) state that for poultry, estimates generated through modelling suggest that nitrogen excretion is one-tenth that of beef (per kg of final meat product) even though the feed crop requirements and associated fertiliser use are not significantly different. However, less grass is required for poultry production.

Around 30% of the reactive nitrogen added to land through agriculture reached the global coastal ocean though the proportion is different according to the river system (Billen et al., 2013). In major systems rivers, such as the Seine, Scheldt and Mississippi, a much higher fraction of nitrogen that has runoff from agricultural land reaches the sea resulting in severe eutrophication in adjacent coastal zones, such as the well-known dead zone present in the Gulf of Mexico.

The spatial organisation of nutrient losses can depend on the location of human populations and the distribution of livestock. Importing feed for livestock creates an excess of nitrogen through manure (Billen et al., 2013). The movement of feed for intensive industrial livestock production can effectively move nutrients from one part of the world to another. These geographical exchanges in nutrients can result in nutrients being 'decoupled' from source to sink. For example, 85% of the net anthropogenic input of reactive nitrogen occurs on 43% of the land area. This decoupling of crop and livestock production is thought to greatly increase losses of nitrogen and phosphorus to the environment as nutrients are not replenished in the area in which they are derived.

Algal blooms and 'dead zones'

In areas of eutrophication, dominant algae are able to 'bloom' due to the fact that they have enough nutrients for their populations to increase rapidly. In a bloom, the algae die and decompose and oxygen is quickly depleted (due to the stimulation of microbial activity and oxygen use during this decomposition). Oxygen is not replenished quickly enough from the atmosphere, or by mixing of more oxygenated waters from adjacent areas (particularly if the water is highly stratified – layered due temperature and/or salinity differences – and cannot mix). When oxygen is depleted in water, few species other than microbes can survive in it. Thus, areas can become 'dead zones' that are devoid of most life. These areas are also known as zones of hypoxia (low oxygen), anoxia (no oxygen) or oxygen minimum zones (sometimes known as OMZs).

The number, size and severity of hypoxic areas, or 'dead zones', in the oceans have increased in previous decades. Though some hypoxic areas occur through natural processes, it is thought that since the 1960s the number of dead zones has approximately doubled every 10 years. According to some scientists, the number of dead zones has increased by 75% since 1992, with more than 600 systems currently (Diaz & Rosenberg, 2008, 2011; and updated in Ripple et al., 2017). The consequences of human-related dead zones are widespread and economically costly. Organisms have different tolerances to inhabiting areas of low oxygen and, therefore, diversity within biological communities is dramatically reduced. In general, hypoxic areas have a reduced ability to functionally transfer energy through trophic levels, particularly to from lower to higher levels, and this can reduce the ecosystem's resilience to other stressors (Diaz & Rosenberg, 2008).

"When oxygen is depleted in water, few species other than microbes can survive in it. Thus, areas can become 'dead zones' that are devoid of most life"

The direct ecological effects of hypoxia are wide and can have economic consequences for human populations. Fisheries are notably affected by the consequences of hypoxia, fish stocks can suffer from die-offs, reduced growth rates, movement to avoid hypoxic areas or increased aggregation and predation pressures (Diaz & Rosenberg 2011). The quantity and frequency of fish kills in the USA has increased in relation to worsening nutrient-related hypoxia along coastal areas (Thronson & Quigg, 2008). Quantifying the economic consequences of die-off is difficult and teasing out the possible contribution from human activities such as livestock production is even more difficult.

Different livestock production systems contribute differing quantities of nutrient pollution to aquatic and marine ecosystems. A life-cycle analysis of beef production in Mexico carried out by Huerta et al. (2016), indicated that extensive production (cattle that are only naturally grazed) had a 25% higher freshwater eutrophication potential than intensive systems. However, intensive production used significantly more water and had the largest contribution to both freshwater and marine ecotoxicity. Manure management in both systems contributed over 99% to total freshwater eutrophication potential. Manure management was also the main contributor to marine eutrophication and corn produced for feed was the second greatest contributor to marine eutrophication. Discharge as wastewater was also a problem and not exclusively to intensive systems where, in some cases, wastewater is treated (Huerta et al., 2016).

In New Zealand, an analysis of the eutrophication potential (EP) for beef and sheep production systems showed that for both livestock the results were highly variable, but on average, beef systems showed around twice the EP of sheep production (Zonderland-Thomassen et al., 2014). This may be due to differences in gaseous emissions at the farm level associated with manure being deposited on pasture as well as leaching.

Industrial-scale poultry and pig production systems are also responsible for nutrient pollution in both surface and groundwater. Mallin et al. (2015) sampled seven watersheds adjacent to industrial poultry and pig production facilities in the USA. Such confined, animal feeding operations (CAFOs) hold ≥ 1000 beef, 2500 pigs (>25 kg), 10,000 pigs (< 25 kg) and 125,000 chickens, 82,000 laying hens or 55,000 turkeys. The large-scale production of animals requires shipping feed from other geographic locations and results in large amounts of excretory nitrogen, phosphorus, organic matter and fecal microbes in the vicinity of the facilities. For instance, waste from pigs is pumped into confinement pits and then periodically sprayed onto surrounding fields which are planted with cover crops (Mallin et al., 2015). In addition to polluting waterways through runoff or seepage, ammonium pollution through volatilisation releases large amounts of inorganic nitrogen to the atmosphere. Mallin et al. (2015) found high levels of ammonium and nitrates throughout the watershed across the ten dates sampled. Ammonium pollution was highest near spray fields used for pig manure. Both surface and groundwater pollution occurred independently of stormwater runoff as the degree of pollution, including faecal contamination, did not differ significantly between rainy and dry periods. Apart from the animal welfare aspects to such intensive farming, there are clearly a wide range of ecosystem impacts and risks to human health. The human health impacts of industrial meat and dairy farming are covered in Chapter 3 on Health.

Predictions for the future

Bodirsky et al. (2014) have modelled global nitrogen requirements under baseline agricultural conditions that predict reactive nitrogen pollution to rise between 102% and 156% of the 2010 baseline. It was estimated that only under ambitious mitigation, including improvements in crop and animal production and food waste reduction, could nitrogen pollution possibly decrease to 36–76% of the 2010 level. How much these mitigation actions can be used to reduce nitrogen pollution as the global human population increases and diets change is unclear.

Pollution by nutrients as a result of agricultural runoff is very expensive. In 2011, the monetary cost of nitrogen pollution was thought to be 0.3–3% of global gross domestic product (Sutton et al., 2013). In the USA alone, the potential health and environmental costs of nitrogen pollution in the early 2000s ranged from USD 81 to USD 441 billion per year (Sobota et al., 2015). Using global emissions databases, nitrogen cycling models and global trade databases for 188 countries, Oita et al. (2016) estimated the per capita footprint for reactive nitrogen at under 7 kg nitrogen per year for some developing countries to over 100 kg nitrogen per year for some developed nations. The authors found that local nitrogen pollution is driven by demand from other countries.

In a study focused solely on China, anthropogenic reactive nitrogen is predicted to more than double in 2050 in comparison with 2010 levels in a BAU scenario (Gu et al., 2015). China is the world's largest producer of reactive nitrogen in the form of chemical fertiliser. It is thought that a scenario that combined changes in diet and increasing nitrogen use efficiency and recycling could reduce losses of nitrogen to 52% and nitrogen creation to 64% of 2010 levels (Gu et al., 2015). Similarly, options to reduce nitrogen pollution resulting from food production in Europe are covered by Grinsven et al. (2014) where effective strategies include convincing consumers with a Western diet to eat less meat and dairy.

In many areas of the world, pollutants such as phosphorus have accumulated over decades. Livestock production is predicted to increase and some scientists are concerned about the interaction between greater release of nutrients and the impact of climate change. Ockenden et al. (2017) analysed data on phosphorus flux in three agricultural areas of the UK and applied a high-spatial climate model to predict phosphorus emissions under climate change. The authors suggest that in temperate areas where wetter weather conditions are predicted during winter as a result of climate change, there may be greater phosphorus losses (up to a 30% increase by 2050s in comparison to present day). Drastic changes in agricultural systems that would result in a 20–80% reduction in phosphorus inputs may be required to avoid these emissions in future (Ockenden et al. 2017). The authors did not detail what type of changes to agricultural systems might be needed to result in such a large reduction in phosphorus inputs.

Finally, the global eutrophication of freshwater bodies in areas adjacent to intensively farmed land, and the increasing scarcity of water available for human consumption is opening up the possibility of complex modification of the global hydrological cycle (Steffen et al., 2015). Changes to the hydrological cycle could result in a number of effects including reduced availability of water in some areas and flooding in others.

Cattle grazing in the Amazon at Mato Grosso, Brazil

Freshwater use

Freshwater is a necessary component in the production of livestock, dairy and crops. Agriculture in general accounts for around 70% of global freshwater use (Campbell et al., 2017). In 2015, Steffen et al. (2015) assessed the global zone of uncertainty (boundary) for the amount of consumptive blue water (volume of surface and groundwater) use to be within the range of 4,000–6,000 km^3 per year. It was assessed that currently roughly 2,600 km^3 is used per year and, therefore, this boundary is well within what is considered the safe operating space. However, an analysis by Gerten et al. (2013) suggested that if the spatial differences in water flow area are accounted for, the planetary boundary for freshwater may be much lower (~2,800 km^3 per year, range 1,100–4,500 km^3 per year). This estimate would put the current freshwater boundary already in the zone of uncertainty (that denotes increasing risk).

The assessment by Steffen et al. (2015) does not take into account the volume of green water (soil moisture from rainwater) consumed and grey water (the volume of freshwater that is required to assimilate/dilute pollutants due to livestock production). The volume of both blue and green water consumed by agriculture is contentious and there is still no consensus (Campbell et al., 2017). How freshwater demand will change in the future is unknown.

Campbell et al. (2017) state that, *"the growth in livestock production, in particular, increases water consumption owing to the extra demand for water to grow crops used to feed livestock."*

From a freshwater perspective, it is more efficient to obtain calories, protein and fat from plant products rather than animal products, though the types of proteins and fats will differ between these two types of resources. Cassidy et al. (2013) suggest that **if all available crops were directly consumed by humans and not fed to animals, the global calorie availability could be increased by up to 70%.** These authors also suggest that if diets shifted from beef to more poultry and pig meat, more people could be fed per hectare. Hoekstra (2012) suggests that if industrialised nations moved towards a vegetarian diet, the food-related water footprint of humanity could be reduced by around 36%. Ran et al. (2017) suggest that ruminants may play an important role in converting non-edible biomass to human food. However, it is important to note that many livestock systems rely on soya or corn as feed, commodities that can be used to support humans, and the land freed by not feeding these crops to animals could be used to produce diverse and healthy plant-based crops to be directly eaten by humans.

Global water footprint of livestock production

Mekonnen & Hoekstra (2012) estimated the water footprint for eight farm animal categories: beef cattle; dairy cattle; pigs; sheep; goats; broiler chickens; layer chickens; and horses from 1996–2005 in different production systems (grazing, mixed and industrial). The authors calculated the blue, green and grey water footprints and both the indirect footprint from feed and the direct water footprint related to drinking and service water for these animals taking into account local conditions. There were geographic differences in that, in some countries for example the Netherlands, are more likely to have intensive production systems than others, for example the USA.

Around 27% of the water footprint of humanity is related to animal production (Hoekstra, 2012). The total global water footprint due to animal production between 1996 and 2005 was 2,422 giga metres cubed (Gm^3) per year (87.2% green (rainwater), 6.2% blue (surface and groundwater), and 6.6% grey water (to dilute pollutants)) (Mekonnen & Hoekstra, 2012)**.** The majority (98%) of the total footprint comes from the feed that the animals consume. Grazing accounts for the largest share (38%), with maize (17%) and fodder crops (8%) accounting for much less.

Larger blue and grey water footprints are associated with more industrial production systems as concentrated feed takes a larger share in the total feed required in comparison to grazing systems. For grazing systems, the blue and grey water footprints are greater for poultry and pork, than for those for beef (Gerbens-Leenes et al., 2013).

For animal products, the global average water footprint increases from milk -> eggs -> cheese -> chicken -> goat -> pork -> sheep -> beef (Table 2). Different levels of intensity in production have a varying proportion of blue, green and grey water required. It is important to note that the use of these water types will have different impacts on the environment. A change in green water availability can affect the availability of regional surface blue water (Quinteiro et al., 2015). Depleting blue water resources can lead to scarcity in groundwater levels resulting in rivers running dry, increased levels of pollution and wide-scale ecosystem impacts that affect biodiversity (Verones et al., 2013). Increasing usage of grey water relates to larger discharges of eutrophying or toxic compounds to freshwater systems. **By combining all water types, the average water footprint per calorie for beef is 20 times larger than for cereals and starchy roots (Mekonnen & Hoekstra, 2012).**

Per gram of protein, the water footprint of beef is six times larger than for pulses. The results of the study by Mekonnen & Hoekstra (2012) are largely consistent with the findings of others and the methods are considered suitable for such assessments. However, in assessing grey water, only nitrogen is considered by Mekonnen & Hoekstra (2012) and no other pollutants such as phosphorus or agricultural chemicals are included (Ran et al., 2016).

Water resources are sometimes considered the greatest limiting factor in the ability to feed the human population in future (Ran et al., 2016). Weindl et al. (2017) used a global modelling approach to quantify current and future contribution of livestock production with a number of demand and supply scenarios. These scenarios included changing both animal and human diets. The authors concluded that although changes in both human and animal diets were significant in limiting further disturbance to the global hydrological cycle, they were not sufficient to prevent water shortages to future food crops. Human dietary changes may have beneficial impacts on agricultural water consumption, but this may be mainly for green water. Weindl et al. (2017) found that estimating the effects of blue water consumption was particularly difficult and prone to high uncertainties. Therefore, strategies for future food security need to be conservative and incorporate dedicated water protection policies to account for the inherent complexity in assessing projected water availability.

Weindl et al. (2017) state, *"it is important to combine demand-side policies aiming at a transformation of consumption patterns with supply-side interventions, capacity building, dedicated water policies and agricultural research and development to protect aquatic ecosystems and mitigate unsustainable water use that might compromise livelihoods of future generations."*

Water footprints of selected animal products as a weighted global average

Product	Production system	Green water (m^3 per ton)	Blue water (m^3 per ton)	Grey water (m^3 per ton)	Total global average (m^3 per ton)
Beef	Grazing	21,121	465	243	21,829
	Mixed	14,803	508	401	15,712
	Industrial	8,849	683	712	10,244
	Average	14,414	550	451	**15,415**
Sheep	Grazing	15,870	421	451	16,311
	Mixed	7,784	484	20	8,335
	Industrial	4,607	800	67	6,623
	Average	9,813	522	216	**10,412**
Goat	Grazing	9,813	522	0	9,562
	Mixed	9,277	285	4	5,007
	Industrial	4,691	313	18	2,863
	Average	6,691	413	6	**5,521**
Pig	Grazing	7,660	431	632	8,724
	Mixed	5,210	435	582	6,226
	Industrial	4,050	487	687	5,225
	Average	4,907	459	622	**5,988**
Chicken	Grazing	7,919	734	718	9,370
	Mixed	4,065	348	574	4,987
	Industrial	2,337	210	325	2,873
	Average	3,545	313	467	**4,325**
Eggs	Grazing	6,781	418	446	7,644
	Mixed	3,006	312	545	3,865
	Industrial	2,298	205	369	2,872
	Average	2,592	244	429	**3,265**
Milk	Grazing	1,087	56	49	1,191
	Mixed	790	90	76	956
	Industrial	1,027	98	82	1,207
	Average	863	86	72	**1,020**
Cheese	Grazing	5,371	293	241	5,905
	Mixed	3,903	463	377	4,743
	Industrial	5,078	500	406	5,984
	Average	4,264	439	357	**5,060**

Table 2. The water footprints for green water (rainwater), blue water (surface and groundwater) and grey water (freshwater that is required to dilute pollutants) of selected animal products as a weighted global average. Water consumption is given in m^3 per ton of animal meat. Note that different water types will have different environmental impacts. Source: Mekonnen & Hoekstra (2012).

Novel entities: Possible future impacts on humans and the environment

Steffen et al. (2015) do not quantify planetary levels for the concept of novel entities. In the context of livestock production systems, the impact of unpredictable issues, such as pollution, disease, antimicrobial resistance and genetic engineering of livestock and plant feed strains, could be considered as among some of the novel entities that could impact the environment in future.

Chemical pollution

Steffen et al. (2015) consider the widespread global use of chemicals, but imply that there is currently no global level analysis of chemical pollution and its impact, making quantifying a planetary boundary value particularly difficult. Myriad chemicals are produced and released into the environment, resulting in cocktails of substances that affect ecosystem functioning. Many of these chemicals are as a result of agricultural activities (Campbell et al., 2017).

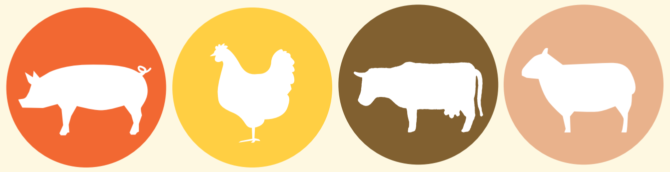
Stehle & Schulz (2015) analysed the impact of global insecticide concentrations and found that concentrations of 50% of the insecticides detected exceeded local regulatory thresholds. Livestock production contributes to the use of some of these substances when pesticides are used to grow feed. Many pesticides are highly biologically active as well as persistent in ecosystems. Numerous reviews attempt to describe and quantify the impact of anthropogenic chemicals on ecosystem functioning, particularly by case studies (for example, Chagnon et al., 2015; Gibbons et al., 2015; Morrissey et al., 2015; Stanton et al.,2018). Livestock manure can also be an important source of substances such as cadmium and arsenic (Cai et al., 2015).

Disease

Novel or particularly virulent strains of diseases are known to be emerging with significant impacts on some wildlife populations (for an example, see chronic wasting disease in Sutherland et al. (2017)). These diseases could be considered novel entities that may impact on biodiversity in the future, but which have consequences that are difficult to quantify and predict.

The dynamics of disease are complex and can rarely be attributed to a single driver. Pathogens often have multiple hosts or reservoirs and the limited knowledge of population dynamics in multiple species can confound our understanding of transmission. However, the persistence of certain diseases at the livestock–wildlife–human interface has long been a threat to meat and dairy production. Farmers can incur considerable economic costs through disease and this can be a particular problem for low-income farmers (Grace et al., 2017). In reverse, livestock are also known to be reservoirs of disease that can be harmful to wild herbivores (Ripple et al., 2015).

The intensification of livestock has, in some cases, been linked to the emergence of food-borne pathogens of humans (zoonoses), such as *Cryptosporidium parvum*, diarrheagenic *Escherichia coli*, *Listeria monocytogenes*, *Campylobacter* jejuni (Perry et al., 2013). These pathogens have few visible effects on their animal hosts or to meat and enter the food chain relatively easily without being detected. Links between the emergence of brucellosis (caused by several species of *Brucella* spp.) and livestock intensification are also discussed by Ducrotoy et al. (2015). However, in some cases production in extensive, outdoor, systems can also facilitate disease transmission, for example bird flu (Perry et al., 2013).



"The intensification of livestock farming has, in some cases, been linked to the emergence of food-borne pathogens of humans"

Movement of livestock can change the spatial dynamics of diseases transmission, for example outbreaks of foot and mouth disease are often associated the transport of infected animals. Climate change is also thought to be influencing disease transmission, with some disease predicted to increase in prevalence, others to decrease (Bett et al., 2017). For some zoonoses, animal husbandry practices, as well as slaughtering and meat storage, have facilitated the spread of the disease. For example, cystic echinococcosis (caused by *Echinococcus granulosus*) is an important disease of both humans and livestock in India, with significant economic and human costs (Singh et al., 2014). Changes to animal husbandry, for example the timing and use of pastures, feeding, hygiene and better waste management, can limit the spread of such diseases.

In many cases the complex processes driving diseases at the livestock–wildlife–human interface are poorly understood by science. How these processes will change with a warming climate in tandem with higher human and livestock population densities adds further difficulties in making predictions for the future (Perry et al., 2013).

Controlling diseases of livestock can result in a number of outcomes for wildlife. Fencing that restricts movement of wildlife and contact with domestic animals, is often used to limit transmission, for example tuberculosis (caused by *Mycobacterium bovis*) between deer and wild boar. Targeting disease vectors is also used and has been the principal method for controlling common diseases of cattle and humans, such as West Nile virus (Gortazar et al., 2015). This type of disease control can entail higher rates of insecticide use and, therefore, is related to other impacts on ecosystems.

In some cases, culling of wild animal populations is used as a method to control both vectors and to limit contact between wild and domestic animals (Gortazar et al., 2015). Substantially reducing certain wildlife populations can have indirect effects on other species. For instance, after badgers (*Meles meles*) were culled in the UK in response to outbreaks of tuberculosis in cattle, fox (*Vulpes vulpes*) populations increased (Trewby et al., 2008). Even though culling is sometimes put forward as a solution to limit transmission, it can have indirect impacts on the target wild animal populations, for example by increased movement of animals due to social disruption, and this can mean that culling is an ineffective disease control method (Gortazar et al., 2015). For further information on livestock-related human disease see Chapter 3 on Health.

Antimicrobial resistance

The routine, extensive and increasing use of antimicrobial products in livestock production has been recognised as an important challenge for animal and human medicine (Van Boeckel et al., 2015). Antimicrobials are routinely used on livestock for a number of reasons: selectively to treat illnesses; regularly as metaphylactics where the whole herd or flock is treated when one individual is ill; as prophylactics when healthy animals are treated during times of stress; for eradication to manage a specific disease or; as growth promoters (Aarestrup, 2015). In some cases, antimicrobials can be a low-cost substitute for hygiene (Van Boeckel et al., 2015). The use of antimicrobials as growth promoters is controversial and has been banned in the EU (since 2006), although this has not led to any significant decrease in antibiotic use (Woolhouse et al., 2015). In Europe, antimicrobial usage is particularly high in intensive farming of pigs and poultry.

The global consumption of all antimicrobials in food animals in 2013 was estimated at 131,109 tonnes of active ingredient (range 100,812–190,492 tonnes) and consumption vary between countries (Van Boeckel et al., 2017). Norway is recorded as using 8 mg per kg of animal product whereas China is thought to use in the region of 318 mg per kg of animal product, making China the largest consumer both in relative and absolute terms.

According to Van Boeckel et al. (2017):
"In 2010, the five countries with the largest shares of global antimicrobial consumption in food animal production were China (23%), the United States (13%), Brazil (9%), India (3%), and Germany (3%). By 2030, this ranking is projected to be China (30%), the United States (10%), Brazil (8%), India (4%), and Mexico (2%)."

This rise in antimicrobial consumption is projected to be due to both a shift in large-scale farms where these substances are routinely used and a growth in consumer demand for livestock products (Van Boeckel et al., 2017).

Antimicrobial resistance is the accumulation of certain genes within microbial populations that increase survival of that species or population. Such resistance is a natural phenomenon that occurred in the pre-antibiotic era, independent of human activities (Hiltunen et al., 2017). However, the repeated and prolonged use of products can result in many different microbes that are resistant to treatments. In 2016, the United Nations recognised that overuse of antimicrobials in livestock production was the primary cause of rising antimicrobial resistance. Particularly concerning is evidence that strains of pathogens such as *Campylobacter* spp. and *Salmonella* spp. are resistant to treatment.

Antibiotic resistant genes are often carried between organisms on mobile genetic elements (plasmids, transposons or integrons). These fragments of DNA are then vectors that transfer genetic information for resistance between bacteria, or even between species (Hiltunen et al., 2017). Whole genome sequencing can identify the origin of particular resistant strains and is revealing significant two-way transfers of resistant bacteria between livestock and humans (Woolhouse et al. 2015).

According to Van Boeckel et al. (2017), limiting meat consumption by adhering to national nutritional guidelines may be a way of reducing the use of antimicrobial productions. For example, a reduction in meat intake to 40 g per day globally could reduce the global consumption of antimicrobials in food animals by 66% (Van Boeckel et al., 2017). The impact of antimicrobial resistance on human health is covered in more detail in Chapter 3 on Health.

An intensive pig farm in Germany

In addition to the impact of antimicrobial resistance on domestic animal and human health, it has also been implicated in affecting soil microorganisms, potentially leading to ecosystem-level changes. Wepking et al. (2017) carried out an assessment of soil microbial communities on 11 farms in locations with regular exposure to manure from cattle treated with antibiotics. Significant differences were seen in the composition of microbial communities – microbes known to exhibit resistance were more abundant in locations treated with manure.

DNA sequencing also revealed a greater abundance of antibiotic resistance in the locations on which cattle manure had been applied. For example, the resistance gene *ampC* was 5.2-fold greater in the manure-exposed locations which the authors suggest could have been due to the use of cephalosporin antibiotics in the dairy herds. The presence of the *ampC* gene was positively correlated with indicators of microbial stress. Wepking et al. (2017) suggest that manure from cattle treated with a bactericide antibiotic could lead to higher microbial respiration of soil carbon and that this may alter ecosystem functioning and carbon cycling.

“Pig manure is a major source of resistance genes and presents both an environmental and a public health hazard

The findings of Wepking et al. (2017) are consistent with those of a study in China that focused on antibiotic resistance genes found in manure derived from pig farms. Zhu et al. (2013) assessed the types and abundance of genes conferring antibiotic resistance at three stages of manure processing at three intensive-scale (10,000 pigs) production systems. The authors found that antibiotics and certain metals that are used as feed additives (for example, zinc, copper and arsenic) were found in all manure samples, creating a complex mixture that may present strong selective forces for resistant genes in microbes. Zhu et al. (2013) found that the abundance of antibiotic resistant genes was directly correlated with antibiotic and metal concentrations with the top six resistant forms of genes being enriched up to 90,000-fold in manure (median 189-fold). The authors implicate processes such as horizontal gene transfer as a method of such enrichment as these resistant genes were closely associated with mobile genetic elements. Clearly, pig manure is a major source of resistance genes and presents both an environmental and a public health hazard. Beyond current peer reviewed scientific literature, even the Food and Agriculture Organisation of the United Nations (FAO) and the World Health Organisation (WHO) have grave concerns over the issue of antimicrobial resistance and call for co-ordinated action from governments.

Gene-edited livestock

Livestock are now the focus of gene-editing research and development using the new wave of genomic tools, such as transcription activator-like effector nucleases (TALEN) and clustered regularly interspaced short palindromic repeats/Cas9 system (CRISPR/Cas9). These tools allow researchers to engineer livestock for disease resistance (Bishop & Woolliams, 2014), to produce more meat (Proudfoot et al., 2015), more desirable milk products (Świątkiewicz, et al., 2015; Whitelaw et al., 2016) and a number of pharmaceutical products (Bertolini et al., 2016). Gene-editing is also being investigated as a tool to make livestock less environmentally damaging, with fewer nutrient emissions. Like any new technology in early development, the positive impacts are often highlighted while the negative impacts are ignored or not yet researched. **For Greenpeace, strict adherence to science and the precautionary principle is essential to avoid generating unintended negative consequences (EEA, 2013).**

The CRISPR/Cas9 system consists of a small RNA molecule that directs the system to a specific sequence of DNA and the Cas9 enzyme snips through the DNA like a pair of molecular scissors. In some cases, the natural repair system will attempt to repair the break, but with an increase in mutation rates at the particular site this can knock out transcription of the gene completely. Subsequent to its first inception, the CRISPR/Cas9 system has been used for a number of other gene-editing methods, including increasing the expression of targeted genes and altering epigenomics (DNA methylation patterns) (Ledford, 2016). This system has the ability to edit single-base pairs, inducing point mutations with accuracy.

The impact of gene-edited livestock strains on natural wildlife populations and ancient/traditional livestock breeds is unknown. Most livestock species are known to have low genetic diversity due to selective breeding and genetic engineering has been proposed as a solution to the reduction in genetic variation (Kristensen et al., 2015; Petersen, 2017).

The new wave of gene-edited livestock of the future will be free from ‘foreign’ sequences, unlike conventional transgenic animals, and so will be difficult to monitor and track throughout production systems. Ruan et al. (2017) suggest that off-target editing is also possible, and a potential concern even with the newest genome editing techniques (for example, CRISPR/Cas9). As gene-editing technology rapidly advances, policy lags behind and most countries do not have laws to regulate the production and sale of products from these animals (Ruan et al., 2017).

Concluding remarks on the environmental impacts of livestock

Agriculture may be responsible for one-sixth of all species losses globally, and may be one of the greatest contributing factors influencing contemporary extinction rates (Barnosky et al., 2011). Current species losses across all biomes on Earth suggest that a sixth mass extinction is now underway.

In 2011 there were 3.6 billion domestic ruminants on Earth – 1.4 billion cattle, 1.1 billion sheep, 0.9 billion goats and 0.2 billion buffalo (Ripple et al., 2014b). Over the past 50 years, an average of 25 million domestic ruminants have been added to the planet every year.

Livestock production has greatly contributed to pushing three of the nine planetary boundaries out of the theoretical 'safe operating zone': land system change; biosphere integrity; and biogeochemical flows, i.e. nitrogen and phosphorus pollution. According to Steffen et al. (2015) freshwater use is currently quantified as within safe operating limits, but how this will change in future if demand for meat increases is unknown. A further, more elusive boundary, novel entities, is likely to be challenged by increasing microbial resistance due to widespread and routine use of antibiotics and as future livestock are designed through 'gene editing' for specific economically desirable traits. The impact of transgressing the boundary concerned with novel entities is entirely unpredictable.

According to Eshel et al. (2014), beef requires 28 times more land per kg of meat than dairy, pork, poultry and eggs. Foley et al. (2011) suggest that, in a 2011 analysis, the land area required for livestock production (crop and pasture land combined) amounts to 75% of all agricultural land. This could equate to 26% of the terrestrial surface of the Earth and the need for such vast areas of land means that there is direct competition between livestock production and land for crops that are consumed by humans, and widespread impacts on biodiversity (Ripple et al., 2014).

During the 50-year period from 1960 to 2011, the production of all animal products was responsible for 65% of global land use change and the expansion in cultivated land (Alexander et al., 2015). Current levels of globalisation mean that the land required to feed the vast number of livestock in production is often not in the country of its consumption (Yu et al., 2013). In many cases, the expansion of land required for growing feed comes at the expense of native forest, grasslands and savannah (Stoll-Kleemann & Schmidt, 2017). The conversion of these natural habitats has brought about profound changes in ecological communities and their functioning.

The intensity of agricultural land-use is strongly correlated with the loss of species. Grazing livestock have long been known to directly impact a wide range of wild taxa, changing community organisation and, in many cases, reducing biodiversity (Hilker et al., 2014; Evans et al., 2015). Cattle production in particular impacts both wild carnivore (persecution) and large herbivore (competition for grazing, disease and hybridization) populations and there is evidence to suggest that the loss of these charismatic and ecologically important animals may be largely due to the expansion of the meat industry.

Crop and livestock systems are also responsible for the greatest perturbation of global nitrogen and phosphorus cycles. According to Bouwman et al. (2013), beef production is known to be responsible for ten times more nitrogen excretion than poultry, even though feed requirements and fertiliser use are not significantly different. Beef is also known to require significantly more phosphorus than other meats. The impact of nutrient leakage into the environment includes eutrophication of freshwater and coastal areas that can lead to zones of hypoxia (low oxygen), anoxia (no oxygen) or oxygen minimum zones. Some of these low oxygen areas are naturally occurring but the number and extent has doubled since the 1960s and many scientist believe this to be as a result of industrial agriculture practices (Diaz & Rosenberg, 2008). These 'dead zones' of low/no oxygen can be devoid of life, as organisms have a differential ability to exist in such conditions.

"In many cases, the expansion of land required for growing feed comes at the expense of native forest, grasslands and savannah"

The total global water footprint for livestock production accounts for 29% of the footprint for all agricultural production (Mekonnen and Hoekstra, 2012). The majority of the water required for livestock production is for the feed that the animals consume. Of a total global water footprint of 2,422 Gm^3 per year (87.2% green, 6.2% blue and 6.6% grey water), 98% is for feed (Mekonnen & Hoekstra, 2012). Grazing accounts for the largest proportion of the water footprint for feed. For animal products, the global water footprint increases from milk -> eggs -> cheese -> chicken -> goat -> pork -> sheep -> beef.

Ran et al. (2016) suggest that water resources are the greatest limiting factor in the ability to feed the human population in the future. Weindl et al. (2017) quantified

Deforestation for cattle farming expansion in Mato Grosso, Brazil

the current and future contribution of livestock production on water demand using a global modelling approach. The authors concluded that although changes in both human and animal diets were necessary, behavioural and production alterations were not enough to protect the global hydrological cycle.

The influence of unknown future perturbations of the planetary boundaries is unpredictable. Novel entities linked to livestock production, such as pollution, disease, antimicrobial resistance and gene-editing could be of concern in future ways which are, as yet, unquantifiable. Antimicrobial resistance is already recognised as threat to human and livestock health by the United Nations (including FAO and WHO). There are also impacts on soil microbe communities that are as yet globally unquantified. The rate at which gene-editing technology is developing will make the cost-effective manipulation of livestock strains for economically important traits a reality in the near future. The scientific community and policymakers do not know how gene-editing technologies will impact wild livestock and there is currently no regulation that can actively manage such technologies.

Changing human diets could make a significant difference to the environmental impacts of our food system. Aleksandrowicz et al. (2016) suggest that, in particular, shifting from a typical Western diet to less meat and more plant-based proteins will be more sustainable given increasing human populations. These authors report, through a meta-analysis, that such dietary changes could reduce land use by up to 70% and water use by up to 50% depending on the type of diets measured (medians for both land and water use were found to be between 20–30%).

This chapter clearly outlines how the effects of industrialised agriculture are not only polluting our planet, but also pushing multiple planetary boundaries to the limit and accelerating the next planetary mass biodiversity extinction. Greenpeace is calling for a food system in which there is not only enough food for all, but one that minimises environmental damage. For livestock, that means that animals are reared respectfully and without suffering, using land that is not required for human food production, while maintaining enough land for biodiversity.

chapter three

Human health impacts of meat and dairy

Introduction

Global meat and dairy consumption has grown rapidly in the past decades (see Figures 4 and 5 in Chapter 1). Global population increase, economic growth, cultural shifts and urbanisation have led to an increased demand for food, particularly of animal origin (Koo et al., 1997; Tilman & Clark, 2014). In spite of regional differences in the level of consumption of different animal products, there are significant concerns among health and nutrition professionals about the health implications of these broad global dietary changes. This chapter examines the evidence on the effects of increased meat and dairy consumption on human health.

Research emphasis to date has been largely on the human health impacts of the consumption of red meat rather than white meat (poultry or rabbit, for example) or dairy.

There are few studies that discuss the associations between white meat consumption and an increased risk of mortality. Some researchers (see Abete et al., 2014) have suggested that more research is carried out to investigate in more detail any associations between health and white meat consumption. In terms of human health, research has shown that white meats, particularly chicken, are associated with a number of negative impacts such as accidental contamination with microbes such as *Salmonella* spp and other issues such as antimicrobial resistance. Health risks associated with microbial contamination, chemical residues, saturated fatty acids and cholesterol will apply to poultry and dairy foods just as they do to red meat.

Fewer studies have investigated the health impacts of dairy consumption relative to meat. Associations between milk consumption and the impact on human health vary in outcome, with no clear consensus on positive or negative effects.

Some research has suggested that funding from industry can influence the scientific conclusions on the health effects of different food products. An analysis that looked at bias in studies related to soft drinks, juice and milk found a strong association between the type of funding available for these articles and the conclusions that were drawn (Lesser et al., 2007). The authors concluded: *"Articles sponsored exclusively by food/drinks companies were four to eight times more likely to have conclusions favourable to the financial interests of the sponsoring company than articles which were not sponsored by food or drinks companies."* (Lesser et al., 2007).

Dietary studies that aim to investigate causation in the associations between certain foods and health outcomes are challenging to carry out. Dietary studies often monitor participants over a period of months, years or even decades and can be open to high levels of variability in terms of lifestyle.

Box 3: Cohort studies and meta-analysis

Some of the most useful studies in identifying health trends related to animal products are longitudinal cohort studies or meta-analyses (for example, Pan et al., 2011b; Rohrmann et al., 2013; Abete et al., 2014; Larsson & Orsini, 2014). Longitudinal cohort studies involve a group (or cohort) of people who share certain characteristics that are monitored over a given period of time to investigate cause and effect, such as development of a disease.

However, there are limitations to cohort studies:

- Correlations may be spurious – an outcome could be linked to a factor that was not measured in the study.
- Data rely on participants to report dietary intake – some foods could be under- or over-reported.
- Not all studies adjust for socio-economic status of participants, which could be a factor that affects the outcome.
- There can be other confounding factors that are not measured. For example, a high intake of processed meat can be accompanied by lower intake of fresh fruit and vegetables.

The benefit of cohort studies that include many thousands of participants and span decades is that associations between diet and outcome are less likely to be due to chance.

A meta-analysis is a method that combines results from different studies to evaluate trends.

Diets rich in meat and dairy

The rise in obesity and chronic non-communicable diseases is prevalent in developed countries, where typical diets include high proportions of animal protein and fats, processed foods and refined sugars (Rouhani et al., 2014; Tilman & Clark, 2014). But low- to middle-income countries are also experiencing a significant rise in obesity and non-communicable diseases as diets shift away from staples such as grains and cereals towards processed foods and animal fats (Thow et al., 2017). The expectation is that those regions will experience rising negative impacts on human health.

Increased consumption of meat, fats and refined sugar have contributed to the increased prevalence of chronic diseases such as type II diabetes, cardiovascular disease and cancers, creating health problems on a global epidemiological scale (Tilman & Clark, 2014).

In particular, available scientific evidence clearly links processed meat and unprocessed red meat consumption with the rise in the global prevalence of non-communicable diseases, which include obesity (Rouhani et al., 2014), and an increased risk of developing type II diabetes (Pan et al., 2011b), colorectal cancer (Bouvard et al., 2015) and cardiovascular disease (Bernstein et al., 2010).

The strength of the scientific evidence led the International Agency for Research on Cancer to classify red meat as 'probably carcinogenic to humans' (group 2A) and processed meat as 'carcinogenic to humans' (group 1) (IARC, 2015).

Examples long discussed in the literature have associated the consumption of red meat with an increased risk of developing diseases such as cancer (Rose et al., 1986; Koo et al., 1997) and cardiovascular disease (Appleby et al., 1999; Gao et al., 1999). Just before the turn of the millennium, red meat consumption was emerging as a major global health concern (Wolk, 2016).

Dietary choices have the potential to confer significant health benefits. For example, **the health advantages of adopting plant-based diets include increased life expectancy** (Singh et al., 2003) **and reduced risk of developing chronic diseases such as type II diabetes, cardiovascular disease and cancer** (for example, Bernstein et al., 2010; Pan et al., 2011b; Song et al., 2016; Seves et al., 2017). There are also other benefits of a plant-based diet that indirectly result from the reduced environmental and climate-related impacts.

Food additives, especially in processed meat, can lead to health problems: the high intake of sodium has been associated with hypertension, and nitrates have been associated with type II diabetes and cancer. Abete et al. (2014) advise readers to be cautious when interpreting the findings from cohort studies because there could be confounding factors at play. High consumption of processed meat was associated with some unhealthy traits such as low intake of fresh fruit and vegetables, lower levels of physical activity and smoking. Abete et al. (2014) also report that people who eat more white meat than red meat have a decreased risk of cancer. Again there could be confounding factors because the people who eat more white meat tend to consume less red meat, therefore the exact reasons for the different health outcome could be complex.

We address specific human health issues related to consumption of meat and dairy in the following section.

"Available scientific evidence clearly links processed meat and unprocessed red meat consumption with the rise in the global prevalence of non-communicable diseases"

Premature mortality

High consumption of processed and unprocessed red meat has been associated with an increased risk of all-cause premature mortality, according to a longitudinal cohort study that ran for approximately 16 years and involved some 0.5 million adults age 50–71 living in the USA (Etemadi et al., 2017). The study also found that substituting a serving of red meat with poultry or fish reduced the risk of early mortality. This study did not investigate health benefits conferred by replacing a portion of red meat with a portion of plant protein such as beans or lentils.

Results of the European Prospective Investigation into Cancer and Nutrition (EPIC) found an association between the consumption of processed meat and increased risk of all-cause mortality. However, they found no association between consumption of unprocessed red meat or poultry and increased risk of mortality. The higher risk of mortality from processed meat could be because these products contain a higher quantity of saturated fats and cholesterol than unprocessed meat, and contain more carcinogenic meat-associated compounds such as polycyclic aromatic hydrocarbons and nitrosamines (Rohrmann et al., 2013).

The consumption of unprocessed white meat (chicken, turkey and rabbit) has not been associated with the same health consequences as red meat (Abete et al., 2014). In women, consumption of white meat was associated with a 5% decreased risk of all-cause mortality – but the authors report that the association was weak and suggest further research is carried out to investigate the associations between eating white meat and early mortality. In this meta-analysis of studies that included male and female participants, consumption of total meat and white meat was not associated with cardiovascular disease (Abete et al., 2014).

High consumption of fruits, vegetables and legumes is associated with a decreased risk of non-cardiovascular and total mortality when compared to low intake of those food items (Miller et al., 2017). This was the conclusion of a global prospective cohort study following 135,335 participants from 18 countries (low, medium and high income).

Non-communicable diseases

The association between consumption of processed meat and/or unprocessed red meat and risk of developing chronic diseases has been established in multiple cohort studies and meta-analyses (for example, Pan et al., 2011b; Pan et al., 2012; Rohrmann et al., 2013; Abete et al., 2014; Wang et al., 2016).

Healthy and unhealthy foods (Imamura et al., 2015)

Diet component	Why 'healthy'/'unhealthy'	
Fruits (100 g/serving)	↓ Coronary heart disease (CHD), ↓ oesophageal cancer, ↓ lung cancer, ↓ stroke	HEALTHY
Vegetables, including legumes (100 g/serving)	↓ CHD, ↓ oesophageal cancer, ↓ stroke	HEALTHY
Nuts/seeds (100 g/serving)	↓ CHD, ↓ diabetes	HEALTHY
Wholegrains (50 g/serving)	↓ CHD, ↓ diabetes	HEALTHY
Seafood (100 g/serving)	↓ CHD, ↓ stroke	HEALTHY
Red meat, unprocessed (100 g/serving)	↑ Diabetes, ↑ colorectal cancer	UNHEALTHY
Processed meat (50 g/serving)	↑ CHD, ↑ diabetes, ↑ colorectal cancer	UNHEALTHY

Table 3. Foods that can have an impact on the risk of developing non-communicable diseases (CHD is an abbreviation of coronary heart disease). From: GLOPAN, 2016. Global Panel on Agriculture and Food Systems for Nutrition. 2016. Foresight report: Food systems and diets: Facing the challenges of the 21st century. London, UK. 132 pp.

Processed meat and red meat products are high in saturated fats, cholesterol and other compounds (for example, heme iron or nitrates, discussed later). These substances can increase the risk of mortality and ill health from non-communicable diseases. Examples of diseases associated with meat intake and other food products include diabetes, colorectal cancer and coronary heart disease (Table 3).

In contrast, consumption of fruits, vegetables, legumes, whole grains and/or nuts is associated with reduced risk of developing coronary heart disease, diabetes, stroke and certain types of cancer (see Table 3 for specific details). A high intake of whole grains (three servings per day) is associated with a reduction in risk of death from all causes, from cancer and from cardiovascular disease (Wei et al., 2016).

Meat, poultry, fish, eggs and the risk of cancer

In the judgement of the Panel[1], the factors listed below modify the risk of cancer. Judgements are graded according to the strength of the evidence.

	DECREASES RISK		INCREASES RISK	
	Exposure	Cancer site	Exposure	Cancer site
Convincing			Red meat[2]	Colorectum
			Processed meat[3]	Colorectum
Probable			Cantonese-style salted fish[4]	Nasopharynx
Limited – suggestive	Fish	Colorectum	Red meat	Oesophagus, Lung, Pancreas, Endometrium
	Foods containing vitamin D[5,8]	Colorectum	Processed meat	Oesophagus, Lung, Stomach, Prostrate
			Foods containing iron[5,6]	Colorectum
			Smoked foods[7]	Stomach
			Grilled (broiled)or barbecued (charbroiled) animal foods[7]	Stomach
Substantial effect on risk unlikely	Non identified			

1. The Panel refers to scientists appointed by the World Cancer Research Fund and the American Institute for Cancer Research to review the literature **2.** The term 'red meat' refers to beef, pork, lamb and goat from domesticated animals. **3.** The term 'processed meat' refers to meats preserved by smoking, curing or salting, or addition of chemical preservatives. **4.** This style of preparation is characterised by treatment with less salt than typically used and fermentation during the drying process due to relatively high outdoor temperature and moisture levels. This conclusion does not apply to fish prepared (or salted) by other means. **5.** Includes both foods naturally containing the constituent and foods which have the constituent added. **6.** Although red and processed meats contain iron, the general category of 'foods containing iron' comprises many other foods, including those of plant origin. **7.** The evidence is mostly from meats preserved or cooked in these ways. **8.** Found mostly in fortified foods and animal foods.

Table 4: The risk of developing cancer from dietary sources. Source: WCRF/AICR, 2007.

Cancer

The International Agency for Research on Cancer announced in 2015 that it had classified red meat as 'probably carcinogenic to humans' and processed meat as 'carcinogenic to humans'. The evaluation was based on a report compiled by a working group of 22 experts in the field from ten countries who assessed more than 800 studies. The conclusion states that every 50 g daily intake of processed meat increases the risk of colorectal cancer by 18% – in short, eating processed meat causes colorectal cancer (Bouvard et al., 2015; IARC, 2015).

Results of meta-analyses and cohort studies associate the consumption of processed and unprocessed red meat with increased risk of developing some cancers, including colorectal, stomach, liver, lung, bladder, pancreas and oesophageal (for example, Boada et al., 2016; Lippi et al., 2016; Wang et al., 2016).

In 2007, the World Cancer Research Fund and the American Institute for Cancer Research reported convincing evidence that consumption of red meat and processed meat increases the risk of colorectal cancer (Table 4) (WCRF/AICR, 2007).

In a meta-analysis of prospective cohort studies, Wang et al. (2016) found that consumption of processed and unprocessed red meat was associated with increased risk of total mortality and death from cancer and cardiovascular disease. **Eating one serving of processed meat every day was associated with an 8% increase in the risk of mortality from cancer when compared to those with little/no processed meat consumption**. The authors suggest that meat-associated compounds, such as polycyclic aromatic hydrocarbons and heterocyclic amines, that form when meat is cooked at high temperatures could be carcinogenic to humans (Wang et al., 2016).

Sinha et al. (2009) found an inverse association between white meat consumption and increased risk of all-cause mortality and cancer mortality. When comparing the group that ate the most white meat compared to the group that ate the least white meat, the group that consumed the most white meat had a lower risk of developing all-cause and cancer mortality than the group that ate the least amount of white meat. In this study, white meat was specified as chicken, turkey and fish.

Cancer and dairy

In its 2007 report, the World Cancer Research Fund and American Institute for Cancer Research (WCRF/AICR, 2007) concluded that milk may protect against colorectal cancer. Dairy intake was also associated with a probable decrease in colorectal cancer by the World Cancer Research Fund's Continuous Update Project (CUP) Matrix (WCRF, 2017). Another study in the USA found that consumption of dairy products may decrease the risk of developing rectal cancer, and that calcium intake may decrease the risk of colon cancer and colorectal cancer (Tantamango-Bartley et al., 2017).

Although there has been evidence suggesting that a diet high in calcium is a cause of prostate cancer, the World Cancer Research Fund and American Institute for Cancer Research (WCRF/AICR, 2007) concluded that there was only limited evidence suggesting that consumption of meat and dairy (known sources of dietary calcium) causes prostate cancer.

The World Cancer Research Fund's Continuous Update Project Matrix has not yet found evidence that associates dairy intake with any other type of cancer (WCRF, 2017).

Type II diabetes

Diabetes is a significant global health issue. An estimated 422 million people globally had the disease in 2014, which is a 290% increase from 1980 when an estimated 108 million people had the disease (WHO, 2017a).

Globally, approximately 90% of people with diabetes have type II, which can be prevented or managed through dietary choices and exercise (Lean et al., 2017). In the USA, an estimated 9.4% of the population had diabetes in 2015, 90–95% of those cases were type II diabetes (Centers for Disease Control and Prevention, 2017). In England, 9% of the adult population had diabetes in 2015 (Public Health England, 2016).

Consumption of one serving per day of unprocessed, processed and total red meat was associated with an increased risk of developing type II diabetes by 12%, 32% and 14%, respectively (Pan et al., 2011b). This study analysed data from three large groups of health professionals living in the USA, following them for a maximum of 20 years, 28 years and 19 years, respectively. The data includes answers to questions relating to red meat consumption. Standard serving sizes were specified as 85 g for unprocessed red meat, 45 g for a hot dog, 28 g for two bacon rashers and 45 g for one item of any other type of processed red meat.

Cardiovascular disease

Globally, 15.3 million deaths (one-third of all deaths) are attributable to cardiovascular disease. Cardiovascular disease is a general term for diseases of the heart and the blood vessels and includes stroke, coronary heart disease, aortic disease and peripheral arterial disease (NHS, 2016).

Eating processed meat is associated with an increased risk of all-cause mortality, according to a meta-analysis of 13 cohort studies from Europe, the USA, Australia and Asia (Abete et al., 2014). The study participants with the **highest processed meat consumption had 22% and 18% higher risk of mortality from any cause and from cardiovascular disease**, respectively, than the participants with the lowest processed meat consumption.

Further, the study also found that eating processed and red meat was associated with a weak increased risk of mortality from cardiovascular disease (Abete et al., 2014). The authors suggest that the increased risk may be because of compounds found in red meat: cholesterol, saturated fat and heme iron.

The consumption of red meat, both processed and unprocessed, was also significantly associated with an increased risk of cardiovascular, all-cause and cancer mortality in a recent meta-analysis (Wang et al., 2016). Similarly, red meat (processed and unprocessed) was associated with an increased risk of total stroke and ischemic stroke in a meta-analysis by Kaluza et al. (2012) of six prospective studies that included a total of 329,495 participants.

Consumption of red and processed meat in women is associated with an increased risk of developing coronary heart disease (Bernstein et al., 2010). The authors suggest that changing the source of dietary protein to foods such as nuts or fish could have health benefits.

People who consume high quantities of red meat (median 62.5 g per day) have an increased risk of mortality from all causes, cancer and cardiovascular disease mortality than people who eat lower quantities of red meat (median 9.8 g per day) (Sinha et al., 2009). This study analysed ten years of data (1995 to 2005) from almost half a million residents of the USA (age 50 to 71 at the start of the study) who took part in the National Institutes of Health–AARP Diet and Health Study. Early death from cardiovascular disease could be reduced by 11% in men and 16% in women by shifting from high red meat consumption (median 62.5 g per day) to low red meat consumption (median 9.8 g per day) (Sinha et al., 2009).

In conclusion, scientific evidence suggests an association between consumption of red meat and processed meat with cardiovascular disease, across ages and gender. Evidence suggests that a diet rich in fruits, vegetables, nuts, legumes and whole grains is associated with reduced risk of coronary heart disease (Table 3).

Cardiovascular disease and dairy

Dairy products are high in saturated fat and cholesterol, which has led some researchers to question the health impacts of dairy foods. Dairy products contribute, on average, 27% of the saturated fat intake to the UK diet. However, a 2015 study found no association between the consumption of milk and other dairy products (not including butter) with an increased risk of cardiovascular disease (Lovegrove & Hobbs, 2015). These authors conclude that the biochemical reasons that dairy products seem to be beneficial for cardiovascular health are unclear, and in terms of maintaining cardiovascular health the evidence to date does not point to removing dairy products from the diet.

Talaei et al. (2016) studied the consumption of dairy products in a large group of Chinese adults living in Singapore. The median dairy intake was 20.1 g per day, and 80% of this dairy intake was milk. More than half (67%) of the respondents never or rarely drank milk. This study reported a slightly lower risk of death from cardiovascular disease in the group of respondents with higher dairy consumption. It also found an inverse relationship between dairy intake and stroke mortality when comparing people with the lowest and the highest dairy intake.

Cheese intake in a developing country (Iran) showed no association with risk of developing cardiovascular disease. The authors noted a negative association between cheese intake and incidence of metabolic syndrome (a term referring to diabetes, high blood pressure and obesity). The biological mechanism for the findings was not discussed (Sadeghi et al., 2014).

Chen et al. (2016) looked at replacement of dairy fats with other food types in relation to risk of developing cardiovascular disease in three large cohorts of adults living in the USA. The study found that dairy fat was not associated with an increased risk of developing cardiovascular disease in any cohort.

Replacing dairy fat with equivalent calories from vegetable fat was associated with a 10% reduced risk of developing cardiovascular disease and an 8% reduced risk of stroke. Replacing dairy fat with starch or sugar was not beneficial in reducing health risk. Replacing dairy fat with other types of animal fat, such as from red meat, predicted a modest 6% higher risk of cardiovascular disease. **Replacing dairy fat with carbohydrates from whole grains (on a calorie basis) was associated with a 28% lower risk of cardiovascular disease**.

Myocardial infarction (heart attack)

Myocardial infarction (medical terminology for heart attack) has been associated with diet, including regular consumption of red meat. Myocardial infarction can be caused by coronary heart disease (NHS, 2016).

Research in Costa Rica between 1994 and 2004 has shown that people who eat one daily portion of red meat (processed or unprocessed, beef, lamb, pork or veal) were 31% more at risk of heart attack than people who only ate 1.5 portions of any red meat per week (Wang et al., 2017). The association between meat intake and heart attack was found to be stronger in women than men. In terms of weight of meat consumed, the respondents in the group that ate the most meat consumed a median 110.8 g per day of total (processed and unprocessed) red meat. The people who ate the least meat consumed a median 19.5 g per week of total red meat. People who substituted 50 g of total red meat intake with 50 g fish, chicken or milk had a lower percentage risk of acute myocardial infarction. For example, replacing 50 g of processed red meat with 50 g of fish was associated with a 39% reduction in risk of acute myocardial infarction (Wang et al., 2017). This study did not consider substitution of a portion of red meat with a non-meat alternative, such as pulses or nuts.

A Danish study that followed more than 55,000 men and women age 50–64 for 13.5 years and living in Denmark found that replacing red meat with vegetables or potatoes significantly reduced the risk of heart attack in women. The study found a similar result in men, but the results were not statistically significant.

Diverticulitis

Diverticulitis is medical condition that occurs in the digestive system in which the diverticula (which are pockets that develop in the lining of the large intestine) become inflamed. A study by Cao et al. (2017) found that men who ate red meat, particularly unprocessed red meat, were at increased risk of developing diverticulitis. The study group, 46,461 USA male health professionals, were age 40–75 when enrolled in the 26-year study (1986–2012).

Substituting one portion of red meat with fish or poultry reduced the risk of developing diverticulitis. In terms of the number of portions of meat eaten by the participants in the study, the authors report that the median intake of red meat (processed and unprocessed) was 1.5 servings per week in the group that ate the least meat, and 12.4 servings per week in the group that ate the most. **Consumption of just one serving of red meat per week increased the risk of developing the diverticulitis when compared to not consuming red meat.** The risk of developing the disease increased with each portion of red meat eaten per week, up to six portions, which was when risk reached a plateau (Cao et al., 2017).

Chronic liver disease

Red meat, both processed and unprocessed, is associated with early mortality, according a large-scale longevity study (Etemadi et al., 2017). In particular, the most significant association was between the consumption of red meat, especially processed red meat, and chronic liver disease.

Etemadi et al. (2017) analysed data from the NIH-AARP study, which comprised responses from 536,969 people over a 16-year period (a total of 7,540,835 person years of follow-up). The authors noted that their study primarily considered processed red meat and not processed white meat because there is little of the latter on sale. They added that the increasing popularity of processed white meat warrants a dedicated study to evaluate the health effects.

Obesity

Obesity is a major risk factor in type II diabetes and heart disease.

Eating red and processed meat is directly linked with obesity, a higher body mass index and an increased waist circumference, according to a meta-analysis of 18 papers and a systematic review of 22 papers that included studies from developed and developing countries (Rouhani et al., 2014). The authors suggest that the high energy, cholesterol and saturated fat content of red and processed meat are possible causes of the association. Other factors that are likely to contribute to the prevalence of obesity include the high consumption of processed foods, sugars and refined grains in typical Western diets.

Pereira et al. (2002) found that dairy consumption in overweight young adults (age 18–30) living in the USA had a positive effect on reducing the risk of insulin resistance syndrome and may reduce risk of type II diabetes and cardiovascular disease. There was no association between dairy intake and reduced risk of insulin resistance syndrome among the adults in the same study who had a normal body mass index.

Dairy consumption was inversely associated with the risk of childhood overweight/obesity in a meta-analysis of ten prospective cohort studies conducted in the USA, UK and Australia (Lu et al., 2016). The authors concluded on the need to examine the types of dairy products in relation to the risk of childhood overweight/obesity.

Lactose intolerance

One of the issues surrounding human consumption of dairy products is lactose intolerance. Babies are born with the ability to digest lactose, but as children develop after weaning the ability to digest lactose can decline. Two-thirds of all adults around the globe do not have the ability to digest lactose (Suchy et al., 2010; Szilagyi et al., 2016).

Bone fracture

The association between increased consumption of dairy products and the risk of bone fractures is unclear – some studies report a link, others do not. For example, high milk intake (in excess of 680 g per day) was associated with higher mortality and higher incidence of bone fracture in a cohort of 61,433 women living in Sweden (Michaëlsson et al., 2014).

Contrary to Michaëlsson et al. (2014) are findings reported by Bolland et al. (2015), who found that intake of dietary calcium through dairy products and other foods did not increase the risk of fracture in the general population. More recently, Bian et al. (2018) found that high intake of yoghurt and cheese, when compared to a low intake, was significantly associated with a reduced risk of hip fracture. They had carried out a meta-analysis to assess the effects of different dairy products (milk, yoghurt, cream, cheese and total dairy) on the risk of hip fracture and also reported that associations between milk consumption and risk of hip fracture were inconsistent (in other words, not all studies suggest that milk consumption is statistically significant in reducing the risk of hip fracture). In their discussion, Bian et al. (2018) suggest a low threshold intake of 200 g per day of dairy consumption may be beneficial in reducing the risk of hip fracture, although the effects of a higher threshold of milk intake are unclear.

Bian et al. (2018) raise key issues in their paper. They write that the association between human health and dairy consumption is complex. On the one hand, dairy products contain calcium and vitamin D, both of which are essential for bone health. On the other they acknowledge that some researchers suggest that D-galactose in milk might cause an inflammatory response, which could in turn lead to bone fracture or mortality.

Such inconsistencies in the findings of diary-related health studies highlight the complex nature of such studies and the need for further research.

Beef and pork on sale in a German supermarket

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Chemical compounds associated with meat consumption

Some of the compounds found in meat have been associated with adverse health effects in humans. The most common ones are outlined below.

Glycolylneuraminic acid

A compound that could contribute to human disease is a sialic acid sugar molecule called glycolylneuraminic acid (Neu5Gc). Neu5Gc is present in mammalian tissue although not in humans – the gene that encodes for this molecule is present in humans but it became deactivated around 3 million years ago.

Dietary sources of Neu5Gc are primarily red meat (beef, pork and lamb) and, to a small extent, dairy products. Neu5Gc is not found in poultry. Neu5Gc causes an immune response in humans and when absorbed after eating can lead to chronic inflammation. Over a long period, long-term inflammation may cause arteriosclerosis and type II diabetes.

Some researchers have suggested a mechanism to explain the epidemiological link between red meat consumption and cancer in humans. The theory suggests that Neu5Gc could be involved in non-infectious disease including carcinoma because the presence of Neu5Gc in some human tumours indicates that the source is dietary animal protein because Neu5Gc does not naturally occur in human tissue (Varki, 2010; Samraj et al., 2015; Alisson-Silva et al., 2016).

Heme iron

Heme iron is the most readily absorbed form of iron and is found in mammalian muscle tissue and egg yolk. Iron is an essential element for human health and is necessary for the production of haemoglobin, which is the oxygen-carrying component in red blood cells. Iron deficiency leads to anaemia, which can affect the immune system and cognitive development (Abbaspour et al., 2014). However, there is emerging evidence that overconsumption of one form of dietary iron – heme iron – could be detrimental to human health.

Consumption of dietary heme iron has been associated with diabetes, cardiovascular disease and cancer. Etemadi et al. (2017) analysed data from a cohort study and suggested that the increased risk in developing chronic diseases and early mortality is associated with heme iron and nitrate/nitrate intake. They found that consumption of heme iron was associated with increased mortality from cancer and kidney diseases. A possible mechanism is that dietary heme iron is associated with N-nitroso compounds.

Nitrates and nitrites

Nitrate is essential to life on Earth and is part of the nitrogen cycle. Nitrates are found in green, leafy plants and also in water supplies polluted with nitrogen sources such as fertilisers, manure or sewage. Nitrogen is present in many compounds in the human body and has beneficial effects in humans, including to blood pressure, to blood platelet functioning and to the functioning of muscles during exercise at appropriate levels.

However, ingesting a high level of nitrates is detrimental to health. High intake of nitrates is associated with methaemoglobinaemia in infants (also known as blue-baby syndrome) and possibly with cancer in some populations (Gilchrist et al., 2010). Nitrate intake in humans is also associated with the formation of carcinogenic N-nitroso compounds (see the next section). Ingested nitrate (NO_3) is converted to nitrite (NO_2) by saliva in the mouth. Nitrites can be converted into N-nitroso compounds in the stomach under certain conditions in a process called 'nitrosation'. The nitrosation process can be inhibited by vitamin C or some antioxidants. The International Agency for Research on Cancer concluded in 2010 that, *"ingested nitrate or nitrite under conditions that result in endogenous nitrosation is probably carcinogenic to humans"* (IARC, 2010).

Dietary nitrites are primarily consumed when they have been used as a food additive. Sodium and potassium salts of nitrates and nitrites are added to processed foods such as meat, fish and cheese as a preservative to prevent microbial growth of the bacterium *Clostridium botulinum*, the agent that causes botulism poisoning. Nitrates are also added because they help red meat retain its colour and enhance flavour (potassium nitrite, E249; sodium nitrite, E250; potassium nitrate, E251; sodium nitrate, E252). The European Food Safety Authority (EFSA) guidelines state that the acceptable daily intake for nitrates is 3.7 mg per kg of body weight per day, and the acceptable daily intake for nitrites is 0.06 mg/kg bw/day.

In a cohort study (the NIH-AARP), Etemadi et al. (2017) analysed data from 536,969 people who were monitored over a 16-year period and found that consuming nitrate and nitrite in processed meat was associated with increased risk of death from kidney and respiratory diseases and diabetes.

The mechanism of action of nitrates can cause metabolic problems in the tissues and organs and can lead to the development of chronic diseases including type II diabetes and cancer (Abete et al., 2014).

Nitrates occur naturally in green leafy plants. However, a recent study in Spain found that estimated exposures to nitrates from vegetables are unlikely to result in appreciable health risks (Quijano et al., 2017). Nitrogen can also be found in drinking water that has been polluted from fertilisers used and overused by industrial agriculture or livestock production systems. Pollution can come from a diverse range of sources in open agricultural systems.

N-nitroso-compounds

N-nitroso-compounds (NOCs) are suspected carcinogens. These compounds can form from nitrates and nitrites that are added to processed meat. NOCs can also form during meat processing, such as smoking or curing (Bouvard et al., 2015).

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAH) are carcinogenic compounds that can form during cooking – particularly at high temperatures. Meat that has been cooked over an open flame contains PAH compounds. Note that the formation of PAHs are not exclusive to red meat and can also form on poultry and fish cooked at high temperatures (Bouvard et al., 2015; Wang et al., 2016; Alisson-Silva et al., 2016).

Heterocyclic aromatic amines

Heterocyclic aromatic amines form during cooking – particularly in meat that has been cooked at high temperatures – and could be carcinogenic, though data are inconsistent (Bouvard et al., 2015; Alisson-Silva et al., 2016; Wang et al., 2016).

Saturated fats

Saturated fats are an essential component of the human diet because they are a source of essential fatty acids, provide energy and assist the absorption of certain nutrients. As is also the case with certain other dietary components, eating too many fatty acids can lead to health problems. Overconsumption of saturated fats has been linked with obesity and type II diabetes and can elevate the level of blood cholesterol.

Saturated fats are found in animal-based foods including lamb, pork, fatty beef, chicken (with skin), eggs, cheese, milk, lard and butter. Plant foods that are high in saturated fats include palm oil and coconut oil. Different foods contain varying quantities of saturated fatty acids. With regards to meat, the quantity of saturated fat varies depending on the age of the animal, the breed, the cut and the animal's diet (Alisson-Silva et al., 2016).

The health risks relating to the consumption of saturated fats are disputed in the literature. An expert consultation conducted for the United Nations Food and Agriculture Organisation concluded that saturated fatty acids 'possibly' increase the risk of developing diabetes (FAO, 2010b). But reports from the literature suggest that the risks to health from saturated fats may not be clear cut because different sources of saturated fats may lead to different health outcomes. Here we outline published work assessing the associations between saturated fats and the risk of developing cardiovascular disease or type II diabetes.

Otto et al. (2012) suggest that the dietary source of fatty acids may be key to understanding the impact they have on human health – specifically the relationship between saturated fat intake and the risk of developing cardiovascular disease. They followed 5,209 participants living in the USA. Participants in the study were enrolled in the Multi-Ethnic Study on Atherosclerosis, which ran from 2000–2010, participants were aged between 45 and 84 years old at baseline (the start of the study). Otto et al. (2012) found that participants with a high consumption of saturated fat from dairy foods had a decreased risk of developing cardiovascular disease.

The converse was found for meat consumption; a **high intake of saturated fats from meat was associated with an increased risk of developing cardiovascular disease.** Saturated fat intake from plant sources and butter was not associated with cardiovascular disease risk, but the intake of these two food types in this study was low in relation to total dairy and meat intake to extract conclusions. In their conclusion, Otto et al. (2012) suggest that other nutrients in dairy such as calcium, potassium and phosphorus

"Overconsumption of saturated fats has been linked with obesity and type II diabetes and can elevate the level of blood cholesterol"

could help to counterbalance the effect of saturated fats and could explain why, in this study, dairy was associated with a lower cardiovascular disease risk.

A study by Wanders et al. (2017) also suggests that the source of saturated fat – meat or plant – could be an important factor when considering human health. In a study that used data collected from 5,675 people enrolled in the Netherlands Epidemiology of Obesity study between 2008 and 2012, Wanders et al. (2017) found that only those saturated fatty acids that are found in meat were associated with markers for insulin resistance and secretion – saturated fatty acids from dairy and plant sources were not associated with those markers. Wanders et al. (2017) suggest that the source of dietary fat could be a risk factor for diabetes and suggest epidemiological studies to investigate possible links between saturated fatty acids from meat and risk of diabetes.

Cheese is high in saturated fatty acids and many dietary guidelines suggest limiting consumption. However, evidence suggests that cheese consumption may not be detrimental to health. A meta-analysis (Chen et al., 2017) that evaluated the results of 15 published studies on cheese intake found an inverse relationship between cheese consumption and risk of developing cardiovascular disease (CVD). The greatest reduction in risk of developing CVD was in people who consumed 40 g per day of cheese. The scientists who completed the meta-analysis commented that the studies were mostly from the USA and Europe, implying that extrapolating the results globally may not be appropriate. Chen et al. (2017) suggest that the protein, vitamin and mineral (particularly calcium) content in cheese may convey cardiovascular benefits that counterbalance its fat content.

In the literature, associations between milk consumption and the impact to human health vary in outcome; some studies report adverse associations, others are positive and in some cases the conclusions are not clear cut and may apply only to a particular group of people and not the general population.

The general recommendation from health and nutrition specialists is to limit the amount of saturated fat in the diet. The American Heart Association recommends that the diet of a healthy adult should contain no more than 5–6% of the daily calorie intake to come from saturated fats, which is 13 g in a diet of approximately 2,000 calories per day.[1] In Europe, the British Heart Foundation recommends that an average man should consume no more than 30 g of saturated fat per day and slightly less for women (20 g maximum).[2] Australia's Heart Foundation recommends that saturated fat is 7% of an average adult's total energy intake, which is approximately 16 g in a diet of approximately 2,080 calories per day.[3]

Foodborne diseases

Diseases from foodborne agents can be caused by bacteria, viruses, protozoans, helminths and chemicals. The World Health Organisation estimates that in 2010, the global disease burden caused by foodborne agents amounted to 600 million illnesses and 420,000 deaths (WHO, 2015b). The most frequent foodborne illnesses were caused by norovirus and *Campylobacter* spp. The most common foodborne deaths were caused by *Salmonella enterica* (the bacterium causes salmonella), *Salmonella typhi* (the bacterium causes typhoid fever), *Taenia solium* (the helminth is a pork tapeworm), hepatitis A virus and aflatoxin (from moulds such as *Aspergillus* spp.).

Not all foodborne diseases are associated solely with the consumption of animals or animal products; some are associated with consumption of non-animal foods. Norovirus, for example, is easily spread by poor food hygiene. Exposure to aflatoxins, which are associated with liver cancer, can be from cereals and pulses that have been badly stored and have become mouldy (WCRF/AICR, 2007).

However, data suggest that most cases of foodborne diseases are due to meat and dairy consumption or production. For example, in the UK between 2010 and 2015 the most common cause of foodborne illness in meat and non-meat products was *Campylobacter* spp., with four of five cases caused by infected poultry. The most common cause of foodborne death in the UK according to the UK Food Standards Agency was caused by *Listeria monocytogenes*, a bacterium that is found in unpasteurised milk and cheese, poultry and fish. Other major pathogens in the UK are *Escherichia coli* O157, which is found in cattle and can be spread by contact with faeces of contaminated animals and in contaminated food, and *Salmonella* spp., which is found in poultry and eggs.

Salmonella spp. is one of the most common causes of foodborne illness across the globe (WHO, 2015b). In the UK, *Salmonella* spp. was the cause of half of all foodborne outbreaks of disease in the years 1992–2008 (Gormley et al., 2011).

1. http://www.heart.org/HEARTORG/Conditions/Cholesterol/PreventionTreatmentofHighCholesterol/Know-Your-Fats_UCM_305628_Article.jsp#.WnnL6mZ0eYU
2. https://www.bhf.org.uk/heart-health/preventing-heart-disease/healthy-eating/fats-explained
3. https://www.heartfoundation.org.au/healthy-eating/food-and-nutrition/fats-and-cholesterol/saturated-and-trans-fat

Recommended levels of consumption of protein and animal products

National and international public health institutions produce food-based dietary recommendations based on the available scientific evidence on nutrition. A compilation of food-based dietary guidelines from more than 100 countries can be found on the website of the Food and Agriculture Organization of the United Nations.[1] The consensus from these recommendations points towards the benefits of a plant-based diet rich in fruits, vegetables and whole grains, with limited intake of refined sugars, fats and, to a varying degree, animal products.

Not all national guidelines recommend quantities or maximums of each food type to consume per day. When compared to meat consumption averages per country, it is clear that the global trends point towards excessive consumption of animal products globally, although there are still a few regions where meat consumption is low (Figure 6 in Chapter 1).

In this chapter, we summarise the recommendations from top global health institutions: the World Health Organisation (WHO), the Harvard School of Public Health, the World Cancer Research Fund, the American Institute for Cancer Research and the International Agency for Research on Cancer (IARC).

World Health Organisation

The World Health Organisation's healthy diet fact sheet 394 (WHO, 2015b) outlines the basic principles for a healthy diet for adults. The guidelines, copied verbatim from the WHO website, are reproduced below:

"Fruits, vegetables, legumes (for example, lentils or beans), nuts and whole grains (for example, unprocessed maize, millet, oats, wheat or brown rice).
At least 400 g (5 portions) of fruits and vegetables a day. Potatoes, sweet potatoes, cassava and other starchy roots are not classified as fruits or vegetables.
Less than 10% of total energy intake from free sugars, which is equivalent to 50 g (or around 12 level teaspoons) for a person of healthy body weight consuming approximately 2000 calories per day, but ideally less than 5% of total energy intake for additional health benefits. Most free sugars are added to foods or drinks by the manufacturer, cook or consumer, and can also be found in sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates."

Less than 30% of total energy intake from fats.

1. http://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines

Unsaturated fats (found in fish, avocado, nuts, sunflower, canola and olive oils) are preferable to saturated fats (found in fatty meat, butter, palm and coconut oil, cream, cheese, ghee and lard). Industrial trans fats (found in processed food, fast food, snack food, fried food, frozen pizza, pies, cookies, margarines and spreads) are not part of a healthy diet.
Less than 5 g of salt (equivalent to approximately 1 teaspoon) per day and use iodized salt.

Harvard School of Public Health

The Harvard Healthy Eating Plate was created in 2011 by nutrition scientists at Harvard School of Public Health. The Healthy Eating Plate is a guide based on peer-reviewed literature to promote optimal health and to address deficiencies in the US Department of Agriculture (USDA)'s MyPlate (Figure 15). The Harvard Healthy Eating Plate aims to help people make the best eating choices and adopting a proportional approach to food types rather than calorie content or weight because a person's dietary needs will depend upon age, gender, level of activity and food preferences. It specifically points to the benefits of a plant-based diet with limited intake of red and processed meats.

World Cancer Research Fund and the American Institute for Cancer Research

The World Cancer Research Fund and the American Institute for Cancer Research recommend that diets consist mainly of foods of plant origin with limited intake of foods from animal origin (WCRF/AICR, 2007).

The WCRF/AICR recommendation is for people to eat mainly foods of plant origin. The suggestion is to base meals around plants, not meat or foods of animal origin. The specification for personal intake is to eat at least five different types of fruit and vegetables per day, amounting to at least 400 g based on one portion weighing approximately 80 g. Additionally, they recommend eating unprocessed / wholegrain cereals and pulses with every meal and limiting intake of refined starch (for example white bread, pasta, pizza, white rice, cakes and baked goods). The suggestion is to eat 25g non-starch polysaccharides, which provide dietary fibre, per day (the recommendation does not include foods with added dietary fibre).

The justification for the WCRF/AICR recommendation is that most diets that protect against the risk of developing cancer are predominantly plant based. People who eat a diet based on starchy staples such as rice

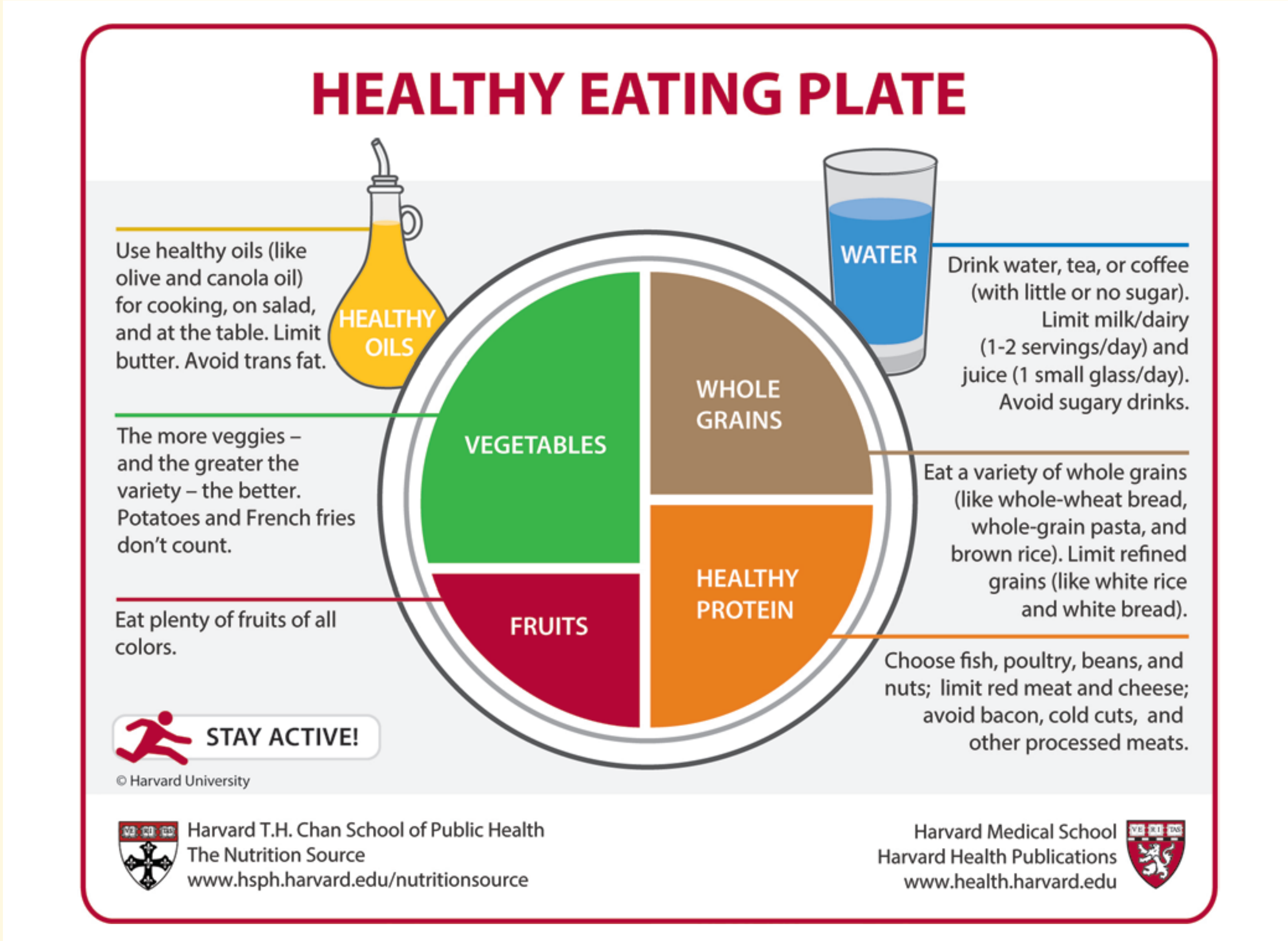


Figure 15: The Harvard Healthy Eating Plate. The Healthy Eating Plate was created by Harvard Health Publishing and nutrition experts at the Harvard School of Public Health. It offers more specific and more accurate recommendations for following a healthy diet than MyPlate, developed by the United States Department of Agriculture and the Department of Health and Human Service. In addition, the Healthy Eating Plate is based on the most up-to-date nutrition research, and it is not influenced by the food industry or agriculture policy. Source: https://www.health.harvard.edu/plate/healthy-eating-plate. © Copyright Harvard University 2011

or tubers such as yam, sweet potato and cassava are advised to ensure that they consume sufficient fruits, vegetables and pulses to avoid nutritional deficiencies.

The WCRF/AICR review panel suggests that red meat does not form part of the daily diet. The justification is that red and processed meat consumption is a probable cause of certain cancers. The panel suggests a goal for public health to limit consumption of red meat to less than 300 g of cooked meat per week – this is because it is at this level of consumption that rates of colorectal cancer are seen to significantly increase. **The panel says that eating any amount of red or processed meat, no matter how small, is associated with an increased risk of developing cancer.**

The panel concluded that current evidence to link consumption of other types of meat and animal products (such as non-red meats, fish, dairy and eggs) and increased risk of cancer was insubstantial. The recommendation was to choose poultry or fish instead of red meat. Meat from wild animals, poultry/birds and fish is recommended over industrially farmed animals because wild meat contains a different nutrient balance.

International Agency for Research on Cancer

The evidence assessed by the International Agency for Research on Cancer (IARC) for Monograph 114 classified red meat as 'probably carcinogenic' and processed meat as 'carcinogenic'. The IARC, which is part of the World Health Organisation (WHO), assessed scientific evidence from 800 studies on cancer in humans. Because the IARC is a research institution, it presents evidence with the intention that the information will be interpreted into dietary recommendations by the WHO and national governments. The latest WHO healthy eating fact sheet (see page 58) does not make specific reference to meat intake (Bouvard et al., 2015; IARC, 2015). But the European Code Against Cancer, which uses the IARC data, advises people to avoid eating processed meat, to limit intake of red meat and to eat plenty of whole grains, pulses, fruits and vegetables.

Health benefits of a diet low in meat and dairy

Published health benefits from plant-based diets include reduced risk of developing chronic diseases such as type II diabetes and cardiovascular disease, and some cancers (for example, Bernstein et al., 2010; Pan et al., 2011; Song et al., 2016; Seves et al., 2017) (also see the summary in Table 3).

Singh et al. (2003) suggest that people who eat a plant-based diet and people who consume meat less than once per week may have increased life expectancy when compared to people who eat meat more regularly.

The WCRF/AICR (2007) concluded that foods containing dietary fibre – such as fruits, vegetables, pulses, roots and tubers – probably protect against colorectal cancer. They also say that non-starchy vegetables and/or fruits probably decrease the risk of developing cancers of the mouth, pharynx, larynx, oesophagus, stomach, lung, liver, pancreas, colorectum, ovary, breast, endometrium and cervix. The risk of developing other cancers may be decreased but the evidence to date is not suggestive. In summary, a diet high in fresh fruit and vegetables can generally be regarded as beneficial in helping to promote good health and to reduce the risk of developing cancers.

Westhoek et al. (2014) predicted various health effects on residents of the European Union (EU) in computer-modelled scenarios that reduced the consumption of meat, dairy and eggs and assumed an increase in the consumption of cereal crops. The study modelled scenarios across 27 EU member states that included the following variations: (1) a 50% reduction in consumption of beef and dairy; (2) a 50% reduction in consumption of pig, poultry and eggs with the consumption of beef and dairy unchanged; and (3) a 50% reduction in consumption of beef, pig, poultry, dairy and eggs. All three reduced consumption scenarios were assumed to have a corresponding 50% reduction in livestock production. Note: sheep and goats were not included in the model.

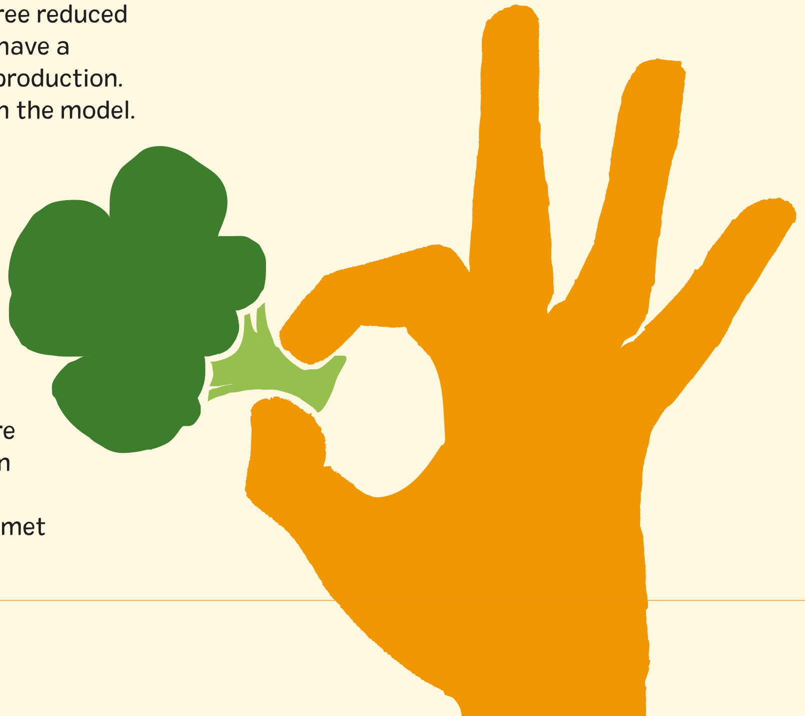
Of the three scenarios, the third one, a 50% reduction in consumption of beef, pig, poultry, dairy and eggs, had the greatest positive impact on human health by reducing saturated fat intake by up to 40% per day. High saturated fat intake is associated with an increased risk of cardiovascular disease and stroke. The authors suggest that there needs to be research into the consumption of micronutrients if meat consumption is reduced so that dietary requirements are met (Westhoek et al., 2014).

Food choices have the potential to confer significant health benefits. Tilman & Clark (2014) **found that adopting a plant-based diet brings an approximately 40% reduction in risk of developing type II diabetes**.

Adopting a plant-based diet that includes fresh vegetables, fruits, nuts and grains has been identified as one way to help treat people with health conditions such as cardiovascular disease. One literature review that suggests healthcare providers increase promotion of such diets also includes analysis of how a plant-based diet can fulfil nutritional needs (Patel et al., 2017). Song et al. (2016) analysed sources of dietary protein from animal and plant sources in a prospective large cohort study. The findings of the study suggest that the source of protein can influence risk of early mortality and reported a weak positive association between the consumption of animal protein and mortality. **The authors found a negative association between consumption of plant protein and early mortality** (Song et al., 2016).

In a cohort study, Pan et al. (2011b) found that the consumption of one daily serving of nuts (28 g), whole grains (one slice of bread or 200 g of cooked brown rice or cereals) and low-fat dairy products (240 ml milk, 28 g cheese, or 120 ml yoghurt) as a protein substitute for one daily serving of unprocessed red meat was associated with a risk reduction of developing type II diabetes by 20%, 24% and 16%, respectively. When substituting one serving of processed red meat with one portion of nuts, whole grains and low-fat dairy, the risk reductions were more beneficial and were calculated as 32%, 35% and 29%, respectively. A reduction in the risk of developing type II diabetes was also associated with substituting one portion per day of processed or unprocessed red meat with one 85 g portion of poultry or fish. Another study that also reported health benefits when replacing red meat with other protein sources was Bernstein et al. (2010), who found that, in a large cohort of women, the replacement of one serving of red meat per day with one serving of nuts, low-fat dairy, poultry or fish was associated with a decrease in the risk in developing coronary heart disease by 30%, 13%, 19% and 24%, respectively. **The health benefit is relatively maximised when red meat is substituted with nuts.**

"Adopting a plant-based diet that includes fresh vegetables, fruits, nuts and grains has been identified as one way to help treat people with health conditions such as cardiovascular disease"



Meeting nutritional requirements from a plant-based diet

A valid concern of many studies and scientists is whether switching to a predominantly plant-based diet will fulfil nutritional requirements.

Seves et al. (2017) modelled a scenario using food consumption data from the Dutch National Food Consumption Survey 2007–2010. The authors modelled three scenarios: (1) no change in meat and dairy consumption (the reference diet); (2) removal of all meat and dairy from the diet; and (3) a 30% reduced consumption of meat and dairy in comparison to the reference diet. Scenarios (2) and (3) included plant-based foods to replace animal products. When compared to meat, plant-based substitutes contained less vitamin A, vitamin D and zinc, but more fibre. Some meat substitutes are high in sodium and many are enriched with iron and vitamin B12. Diet scenario (2) was also characterised by a reduced environmental impact (more than 40%), but was considered nutritionally deficient in zinc, thiamin, vitamin A, vitamin B12 and calcium. Seves et al. (2017) recommended diet (3), comprising 30% less meat and dairy, which would reduce greenhouse gas emissions by 14% and at the same time provide health benefits. However, other studies have found that a properly planned plant-based diet can meet nutritional needs (for example, Craig & Mangels, 2009).

Protein can be obtained from plant foods, though a higher than recommended quantity of foods such as pulses may need to be consumed to obtain sufficient nutrients because plant foods are less energy-dense than animal foods.

Dietary sources of zinc include pulses, nuts, grains and soy. People adopting a plant-only diet may need to eat more than the recommended daily intake of foods containing zinc to compensate for the lower bioavailability of zinc from a plant-only diet when compared to a diet that includes animal products.

Regular intake of vitamin B12 is also essential for a healthy nervous system and to help prevent anaemia (Hunt et al., 2014). People who adopt a plant-based diet that includes some dairy products and eggs (lacto-ovo vegetarians) can readily obtain B12 from sources that include dairy and eggs. Otherwise, in strict plant-only diets, vitamin B12 can be obtained from fortified foods or a supplement (Craig & Mangels, 2009).

Another dietary concern is ensuring that iron is obtained from the diet if meat is reduced or omitted. However, it is possible to obtain dietary iron from a diet that does not include animal products. Non-heme iron (as opposed to heme iron, which is found in mammalian muscle tissue and egg yolk) is available from plant foods including lentils, spinach, kale, nuts and seeds. Non-heme iron is harder for the body to absorb than heme iron from meat so a greater quantity of non-heme iron will be necessary in the diet. Consumption of plenty of fresh fruits and vegetables that contain vitamin C assists the body's absorption of iron from foods.

Calcium deficiency can cause low bone density, which can in turn lead to conditions such as rickets and osteoporosis (Suchy et al., 2010; Lovegrove & Hobbs, 2015; Szilagyi et al., 2016). Health professionals provide advice on alternative sources of calcium in the diet, such as green leafy vegetables (Chinese cabbage, kale and broccoli), soya beans, tofu, nuts, bread and anything made with fortified flour, and fish in which the bones are consumed, such as sardines and pilchards.

A properly planned plant-based diet, in which only plant foods and no animal products are consumed (vegan), is appropriate for people at all stages of life and provides all necessary nutrients, vitamins, minerals and amino acids apart from vitamin B12 (a B12 supplement or foods fortified with B12 might be necessary).

A balanced plant-based diet with a moderate intake of eggs and dairy products (lacto-ovo vegetarian), which is the most common form of plant-based diet, also fulfils all nutritional requirements and is safe and healthy for pregnant and breastfeeding women, babies, children, teenagers and seniors.

How the production of meat and dairy affects human health

Globally, livestock production takes up to 75% of all agriculture land (Foley et al., 2011). As both the world population grows and demand for animal-sourced protein increases, a huge burden will be placed on food production systems to meet this demand.

With a massive amount of land dedicated to livestock production, and production practices that are often very intensive in the use of feed, water, chemicals and medicinal compounds, it is clear that livestock production will directly and indirectly affect human health. Some research has examined the possibility of developing intensive livestock farming that require less farmland, but intensive livestock farming practices can have implications not only on human health but also on the environment and animal welfare (Röös et al., 2017; Swain et al., 2018). For a broad analysis of livestock production on the environment, see Chapter 2. In this section we give a broad compilation of the main human health hazards associated with the rearing of animals.

Pollution of groundwater

Groundwater is a source of water for millions of people around the world and is particularly important for rural communities where no other source of drinking water exists. Pollutants that are discharged to land and surface water as a result of livestock production can reach the aquifers, polluting groundwater sources and potentially affecting the health of people drinking those water supplies. Livestock production, which is a major use of land worldwide, emits a variety of pollutants that can reach the groundwater. Pollutants include nitrates and phosphorus from fertilizers applied to feed crops, antibiotics and microbes present in the manure.

The primary sources of nitrogen pollution are the increasing use and overuse of chemical nitrogen fertilisers and application of livestock manure to agricultural crops. Overuse of chemical fertilisers can result in a situation in which the plants do not take up all the applied fertiliser. The excess can then pollute the atmosphere or waterways (ground water, rivers, lakes and oceans) and lead to eutrophication, which can cause algal blooms (see more on eutrophication in Chapter 2). Wastewater that has been used to irrigate feed crops or animal pastures can contaminate soil and, through runoff, can contaminate rivers and the ocean. Untreated wastewater has been found to contain antibiotics and other compounds used in the livestock farming industry (Tirado & Kruszewska, 2012).

The main ways in which humans are exposed to nitrate and nitrite is dietary exposure (primarily through eating vegetables and cured meats) and drinking water (WHO, 2011). The World Health Organisation established the safety value for nitrate in drinking water as 50 mg/l as nitrate ion (equivalent to 11 mg/l as nitrate-nitrogen) to protect the health of the most sensitive subpopulation – bottle-fed infants. Drinking water that has been contaminated with run-off from chemical nitrogen fertilisers is reported to have affected agricultural areas in certain regions of the USA including Kansas, in which nitrates were found at twice the legal limit in 2014, and 2015 in tap water supplies in a town called Pretty Prairie.

Human health can be affected by nitrates but it is the metabolites of nitrate, and not nitrate itself, that causes the problems. Evidence is emerging that dietary nitrates could help to promote a healthy vascular system and reduce the risk of developing cardiovascular disease (Lovegrove et al., 2017). However, excess intake of nitrate and nitrite can cause health problems through the formation of carcinogenic N-nitroso compounds (McKnight et al., 1999; Santamaria, 2005).

Health risks associated with excess nitrate intake include bladder, thyroid, colon, kidney, ovarian and gastric cancers, and non-Hodgkin's lymphoma. In infants the ingestions of nitrates can be severe causing methemoglobinaemia, or blue-baby syndrome, a condition that inhibits haemoglobin in red blood cells from carrying oxygen and can sometimes lead to asphyxia.

Nitrates are just one form of possible contamination to supplies of drinking water. An increased risk of microbial pollution can arise if humans ingest water that has not been properly treated. For example, a study in Piedmont, Italy, found that the hepatitis E virus (HEV) can be transmitted in drinking water. In the region, untreated water is commonly consumed from public water fountains. The possibility of HEV transmission arises in this region because swine manure is used to treat agricultural fields. If the swine have HEV and their contaminated manure is used to fertilise the fields, water runoff can then contaminate local water supplies (Caruso et al., 2016).

Westhoek et al. (2014) modelled a scenario in Europe in which the reactive nitrogen pollution of waterways and the air could both be reduced by 40% if the consumption of beef, pigs, poultry, dairy and eggs were reduced by 50%. The reduction of nitrogen pollution would be beneficial to human health because it would help to reduce the nitrogen load entering rivers and oceans, which would improve the water quality for freshwater and marine biota and for human drinking.

Chicken farm in northern Germany. 30,000 male and female chickens of the breed "Ross" are fattened in this north German farm within 35 days to a weight of 2 kg

Air pollution

Air pollution in areas close to intensive livestock farms can cause poor air quality because of the emission of coarse and fine dust particles, gases and endotoxins (endotoxins are macromolecules that form the outer membrane of some Gram-negative bacteria). Particulate matter emitted from farms comprises both organic (dust, animal hair, bedding, feathers, animal feed, viruses, fungi, bacteria) and fine inorganic particles ($PM_{2.5}$). $PM_{2.5}$ are particles less than 2.5 µm in diameter, the majority of which are secondary inorganic aerosols such as ammonium nitrate and ammonium sulphate (Smit & Heederik, 2017). Other gases emitted include hydrogen sulphide (Feilberg et al., 2017).

Chemical contaminants

Agricultural activities can release chemical compounds that can affect human health. Agricultural ammonia from chemical fertilizer and animal manure can react differently in the atmosphere depending on temperature and light conditions. Ammonia runoff from fertilizer or manure slurry can cause eutrophication in rivers or lakes. Ammonia released into the atmosphere in gaseous form can contribute to the burden of fine particulate matter ($PM_{2.5}$) contamination and negatively affect human respiratory health (Paulot & Jacob, 2013).

Radon et al. (2007) found that living in close proximity to intensive livestock farms could adversely affect the respiratory health of local non-farm-working residents (the residents reported asthma-like conditions). The study assessed the effect of environmental exposure to air pollution emitted from confined animal feeding on 6,937 adult residents of four German towns located within 500m of intensive livestock farms. In addition to reports of lung problems, 90% of study participants reported being annoyed by agricultural odours.

One study (van Dijk et al., 2016) looked at whether exposure to livestock exacerbates symptoms in people who have chronic obstructive pulmonary disease (COPD) and asthma. The participants in the study lived in areas of the Netherlands with farms that used concentrated animal feeding systems and kept a high number of animals, such as more than 120,000 hens, more than 250 dairy cows or more than 7,500 pigs in intensive production systems. The control group focused on people inhabiting areas with a lower density of livestock farms. The study found that people with COPD who lived within a 500m radius of livestock farms had an increased risk of exacerbated COPD symptoms. Specifically, people with COPD who lived within 500m of poultry farms that kept up to 12,499 chickens had a 36% higher risk of experiencing exacerbated symptoms than the control group. There was no association between livestock exposure and exacerbated symptoms in people with asthma. The study did not include measurements of agents that could have caused the exacerbated symptoms. The authors did not examine the type of housing used in the commercial poultry farms (van Dijk et al., 2016).

Intensive commercial poultry farms or sheds containing laying hens emit organic and inorganic particulate matter – which might include feed, manure, viruses, bacteria, fungi and endotoxins – and odours from gases such as ammonia. Various factors can influence the emission of dust from poultry farms, including feed type, litter, age of the birds and the composition of manure (Dunlop et al., 2013). Following the implementation of EU Directive 1999/74/EC, the improvement in hen welfare in commercial laying hen housing has led to an increase in the dust produced in such farms (Le Bouquin et al., 2013). The directive could have led to an increase in the number of airborne particles in the area surrounding poultry farms that have the potential to cause or exacerbate irritation and/or inflammation of the respiratory system.

Fine particulate matter

Agricultural activities release organic and inorganic particles into the atmosphere and these particles can potentially cause inflammation of the respiratory airways. In Europe, Russia, Turkey, Korea, Japan and eastern USA the agricultural sector is the main source of fine particulate matter ($PM_{2.5}$) (Lelieveld et al., 2015). Emissions from the agricultural sector are mostly inorganic, but the extent to which particulate matter contributes to early mortality will depend on the composition of the matter and the atmospheric chemistry. In the agricultural sector, ammonia (NH3) from chemical fertilisers and livestock can affect the air quality, although the risk to human health from inorganic (non-carbon) agricultural $PM_{2.5}$ will not be as severe as the risk posed by carbonaceous $PM_{2.5}$, which is thought to be five times more harmful (Lelieveld et al., 2015).

A longitudinal respiratory health study by Loftus et al. (2015) monitored 57 school-age children who had been diagnosed with asthma and who lived in a rural area of Washington State where there is a high number of large-scale farms (dairy and orchards). $PM_{2.5}$ concentration tended to be higher in winter because of atmospheric stagnation. This study found that increases in $PM_{2.5}$ led to short-term increases in symptoms (including wheezing and waking during the night) of asthma in the children studied. The study concludes that even though the composition of $PM_{2.5}$ in rural settings might differ from that in urban settings, particulate matter can have a detrimental effect on respiratory health in children. Loftus et al. (2015) suggest that additional research is needed to determine the composition and sources of $PM_{2.5}$ in agricultural regions.

Long-range, post-farm transport of livestock and crops also contributes to $PM_{2.5}$. Carbonaceous $PM_{2.5}$ is, in general, more toxic than inorganic $PM_{2.5}$ because the former will likely contain a higher proportion of incompletely combusted material and heavy metals (Lelieveld et al., 2015). However, regardless of chemical composition, $PM_{2.5}$ can still negatively affect people who have respiratory problems.

Antimicrobial resistance

A global rise in the prevalence of microbes that are resistant to antimicrobial treatments has been reported in scientific literature. The underlying reasons for this are complex because antimicrobial resistance can be driven by a number of factors, including exposure of microbial populations to heavy metals and other chemical contaminants. One of the most important drivers, however, is that the use of antibiotics in the treatment of infections in humans and in livestock is increasing across the world. Overuse and inappropriate use of antibiotics contributes to an increase in resistant microbes. The use of antimicrobials in veterinary medicine is a significant factor in the development of antibiotic-resistant microbes. There are clear potential consequences for human health, particularly in low-income countries that lack the resources to use new-generation antibiotics or alternative therapies (Van Boeckel et al., 2017).

Antibiotics are used widely across the globe, including

for treatment of diseases and, since the mid-1950s, as additives in livestock feed to promote growth. An estimated 63,151 tons of antibiotics were used in food animal production globally in 2010, a figure that is estimated to increase by 67%, to 105,596 by 2030 (Van Boeckel et al., 2015). Since the 1970s, mounting evidence has been published linking the use of antimicrobial additives in livestock feed and antibiotic-resistant bacteria harboured by humans (many studies have been conducted in people exposed occupationally, such as farm workers and veterinarians) (Marshall & Levy, 2011). Transfer of antimicrobial resistance can be through direct contact or through the food chain, in the water supply or airborne. Animals (or humans) infected with bacteria that have developed or acquired resistance to antimicrobials will not respond to antimicrobial medicines (Figure 16 and Figure 17). There is considerable overlap between antimicrobials used in human medicine and in livestock treatment and production (O'Neill, 2015).

Arguably, the best known example of antimicrobial resistance in livestock production is Livestock Associated Methicillin Resistant Staphylococcus aureus (LA-MRSA), which is also known to colonise humans working with animals and may give rise to human infections (Cuny et al., 2015). Another important example is resistance to the Beta-lactam antibiotics (penicillin and cephalosporin) caused by heavy use of these antimicrobials in humans and now emerging in bacteria associated with cattle, poultry and pigs. These bacteria produce extended spectrum beta (β) lactamases (ESBLs), which break down this class of antibiotic (DARC/ARHAI, 2012). This is a particular problem with enterobacteria such as E. coli and Klebsiella spp. but also involves other bacteria. ESBLs have been identified globally. Most recently resistance to colistin, an antibiotic of last resort in human medicine, has been identified in a major study in China, most probably as a result of colistin use in livestock (see O'Neill, 2015).

Intensive industrial farming can also result in the transfer of drug-resistant microbes between animals that are being kept in close proximity (O'Neill, 2016). One estimate quantifies the cost of antimicrobial resistance in the USA as being in the region of US$55 billion per year (Smith & Coast, 2013). Some researchers suggest that this figure is an underestimation because it does not take into account costs to the healthcare system should the worst case scenario happen in which an epidemiological situation arises for which there are no antimicrobial treatments for infections (Smith & Coast, 2013).

The presence of antibiotic-resistant bacteria in livestock and meat products intended for human consumption is known. For example, pigs arriving at an abattoir in Canada tested positive for methicillin-resistant *Staphylococcus aureus* (MRSA) in their nasal cavity, although after slaughter and processing there was a significantly lower presence of MRSA – highlighting the importance of hygienic practices during preparation of meat intended for consumption (Narvaez-Bravo et al., 2016). Poultry meat can be contaminated with *S. aureus* at low levels but good food handling techniques and thorough cooking can prevent infection. Next-generation genetic sequencing is helping to further understanding of the epidemiology of antimicrobial resistance, but additional studies are needed to assess the prevalence and impact to human health of foodborne antimicrobial resistance (Bortolaia et al., 2016; Koch et al., 2017).

Dervilly-Pinel et al. (2017) found residual concentrations of antimicrobial veterinary drugs in 11 of 266 meat (beef,

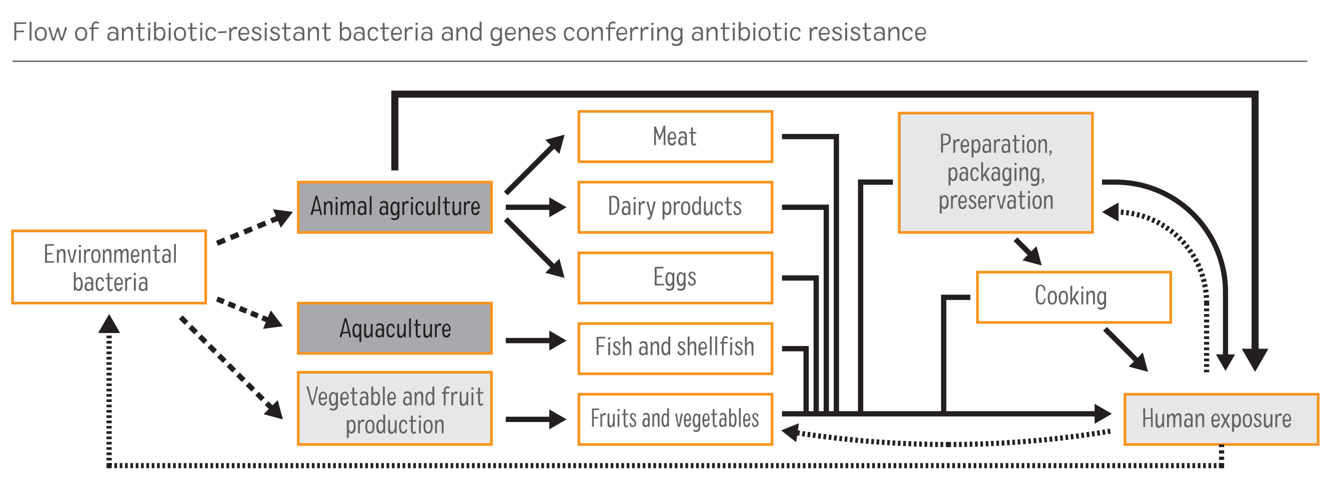


Figure 16: A simplified schematic illustrating the flow of antibiotic-resistant bacteria and genes conferring antibiotic resistance. Boxes shaded dark grey indicate areas in which there is strong selection pressure for resistance, such as use of antibiotics. Boxes shaded with light grey indicate a lesser extent of selection pressure for antibiotic resistance. Source: Bengtsson-Palme, 2017.

Possible routes of transfer of antibiotic resistance from livestock farming to humans

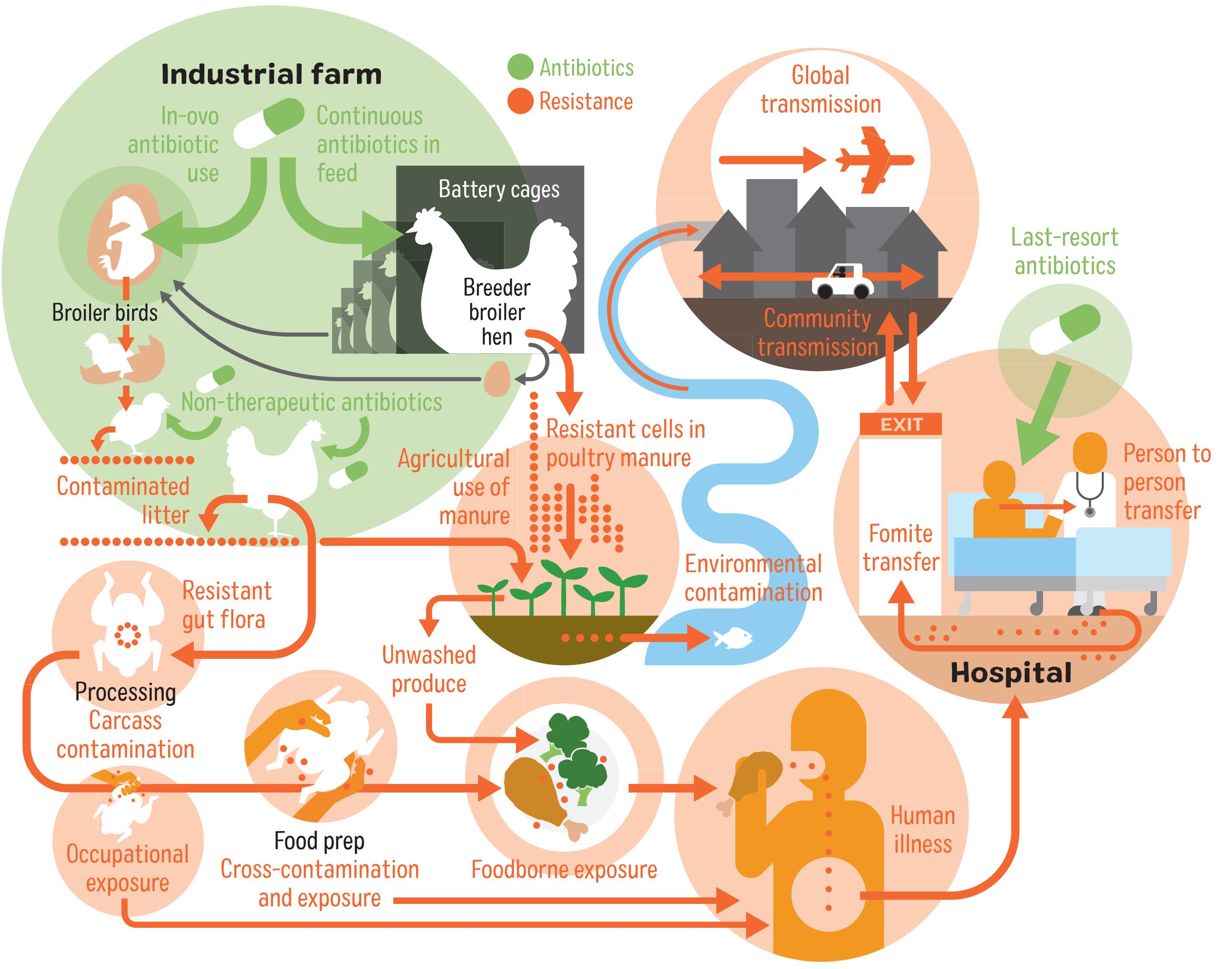


Figure 17: A schematic showing the possible routes of transfer of antibiotic resistance from livestock farming to humans.
The figure shows the 'ecosystem' of antibiotic resistance that links antibiotic resistant bacteria in poultry to humans. From: Koch, B., et al. 2017. Food-animal production and the spread of antibiotic resistance: the role of ecology. Frontiers Ecology and Environment, 15: 309–318. Adapted, with permission, from the original figure by Victor O. Leshyk.

pork, poultry) samples from France that were intended for human consumption. All samples that were tested complied with Commission Regulation (EU) No 37/2010. In another example, an association was found between proximity to intensive pig farming and the infection with MRSA in non-farmworkers in Pennsylvania, USA (Casey et al., 2013).

Tetracycline-resistant bacteria were detected in Danish soils that had been treated with pig slurry, and even though elevated levels of the resistant bacteria were temporary (lasting approximately five months), the authors suggest that continued application of pig manure slurry could contribute to antimicrobial resistance in soil bacteria (Sengeløv et al., 2003).

O'Neill (2016) suggests a broad raft of measures designed to protect against the impacts of antimicrobial resistance. These centre around setting targets to restrict the use of these agents in agriculture and aquaculture, reducing the crossover of antibiotics used in human and animal health to prevent those important in human medicine being used in agriculture, together with increased surveillance of resistance.

The UN World Health Organisation (WHO, 2017b) made broadly similar recommendations based upon a strong precautionary position:

1. Overall reduction in use of all classes of medically important antimicrobials in food-producing animals.
2. Complete restriction of use of all classes of medically important antimicrobials in food producing animals for growth promotion.
3. Complete restriction of use of all classes of medically important antimicrobials in food-producing animals for prevention of infectious diseases that have not yet been clinically diagnosed.

In addition to these strong recommendations they made further suggestions including for future best practice:

1. Antimicrobials classified as critically important for human medicine should not be used for control of the dissemination of a clinically diagnosed infectious disease identified within a group of food-producing animals.
2. Antimicrobials classified as highest priority critically important for human medicine should not be used for treatment of food-producing animals with a clinically diagnosed infectious disease.

On a more regional basis, the European Commission (2017) devised an approach based on a concept of 'One Health' as: *"A term used to describe a principle which recognises that human and animal health are interconnected, that diseases are transmitted from humans to animals and vice versa and must therefore be tackled in both. The One Health approach also encompasses the environment, another link between humans and animals and likewise a potential source of new resistant microorganisms. This term is globally recognised, having been widely used in the EU and in the 2016 United Nations Political Declaration on AMR."*

Zoonotic diseases

Zoonoses are diseases that can transfer from animals to people. Methods of infection include through contaminated animal products or as airborne particulates. An example of a commonly detected zoonosis is *Taenia solium*, or the pork tapeworm. Infection with the larval form of this parasite (cysticercosis) is considered to be one of the major causes of global foodborne deaths. Larval infection is through ingestion of tapeworm eggs. The adult tapeworm infects humans through consumption of undercooked or uncooked pork that has been infected with the larvae (WHO, 2015b).

Creutzfeldt-Jacob disease (CJD) is caused by prions (infectious proteins that are not destroyed by heat or radiation) that can be spread through infected meat products (NHS, 2015). The outbreak of variant-CJD in the UK during the 1980s and 1990s was caused when people consumed infected meat. Speculation remains as to how many people may be currently carrying the disease.

Cases of zoonotic infections are more commonly seen in farmworkers and veterinarians than the general population. There is only limited evidence for infection among the wider human population for diseases that can be transmitted to humans from animals (Caruso et al., 2016). Potential zoonoses include hepatitis E virus, avian flu and psittacosis (psittacosis is a respiratory disease caused by *Chlamydophila psittaci* that is found in birds and can be spread through breathing in airborne particles found in infected faeces).

There are conflicting reports in the literature regarding the risks to the general population of developing a zoonotic disease. For example, Smit & Heedrick (2017) did not find evidence for zoonotic infection in people living near intensive livestock farms, but hypothesised that living in close proximity may predispose residents to respiratory infection through chronic inflammatory processes in the airways. Contrary to that finding, Freidl et al. (2017) found an association between increased risk of pneumonia and living within 2,000 metres of a goat farm or within 1,000 metres of a poultry farm in the Netherlands.

The UK Government has published a list of more than 40 important zoonotic diseases (Public Health England, 2013). Of these, some 24 are designated as reportable diseases (Public Health England, 2017). Of the zoonoses of potential concern in the UK, those associated with agricultural animals include anthrax, avian influenza, brucellosis in cattle, *Echinococcus granulosus*, Newcastle disease, psittacosis, *Salmonella* and tuberculosis. The published data suggest that quantitatively the most important zoonoses reported in the UK as confirmed by laboratory analyses in 2016 were *Campylobacter*iosis (59,105 cases), Cryptosporidiosis (6,722 cases) and non-typhoidal Salmonellosis (10,341 cases). This points to the importance of livestock and livestock products in the cause of certain diseases.

Tomley & Shirley (2009) point out that increases in the emergence and re-emergence of infectious diseases in humans and animals have been reported worldwide over several years. They note that zoonotic diseases account for around 60% of all known emerging infectious agents. Of the newly identified agents, 75% originated in mammals and the prevalence of those new diseases is projected to rise. RNA viruses (a virus that has ribonucleic acid as its genetic material) are considered to pose particular risks because of the trend for ever larger cities. Megacities can then become significant as locations where infectious agents from human and animals can mix.

Concluding remarks on health

The literature on the existing and potential impacts of livestock production and consumption on human health is wide ranging and expanding. Many of the original cohort studies and meta-analyses considered in this review strongly suggest that consumption of both processed meat and unprocessed red meat (beef, pork, lamb and goat) is associated with negative health outcomes. Examples of dietary-related non-communicable diseases include obesity, cardiovascular disease, myocardial infarction (heart attack), liver disease, type II diabetes and cancer.

In 2015, the International Agency for Research on Cancer classified red meat as 'probably carcinogenic to humans' and classified processed meat as 'carcinogenic to humans' after reviewing more than 800 studies. Cancers associated with eating red and processed meat include colorectal, stomach, liver, lung, bladder, pancreas and oesophageal. In comparison to studies on red meat, fewer studies have looked in-depth at associations between poultry and dairy consumption and human health risks, and these remain areas requiring research.

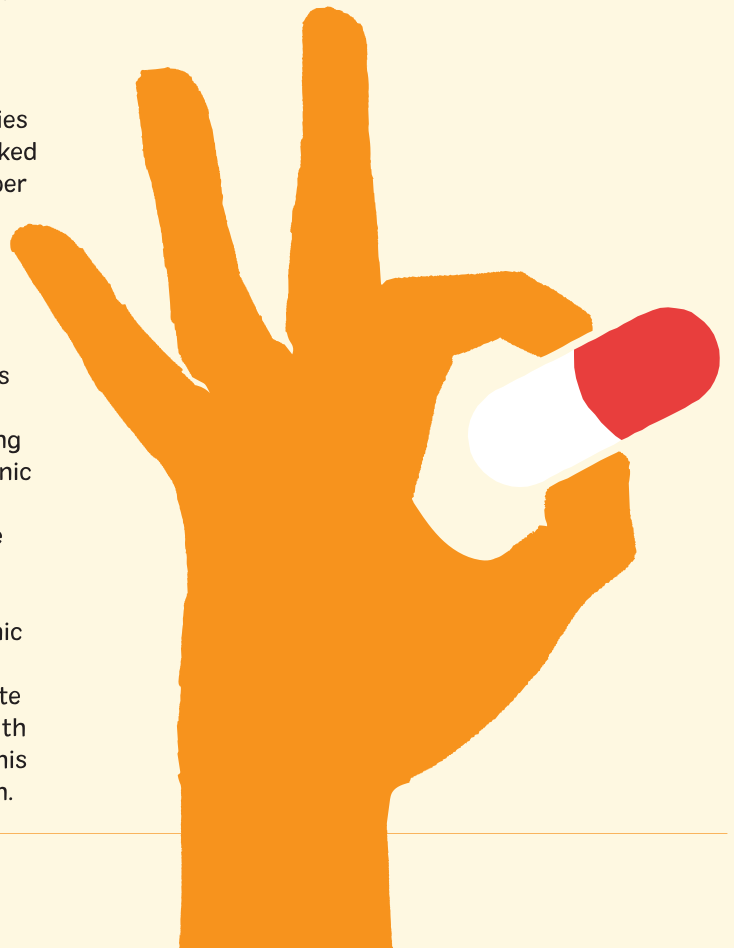
The World Cancer Research Fund and American Institute for Cancer Research currently recommend a personal maximum consumption of red meat not in excess of 300 g per week, with limited processed meat intake. The Harvard School of Public Health recommends limiting the consumption of red meat and cheese, and to avoid eating processed meats such as bacon or cold cuts.

Considerable research effort is now being directed at building upon the findings from epidemiological studies to identify biochemical mechanisms that can be invoked within the body following meat consumption. A number of harmful compounds found in meat products have been associated with meat consumption. For example, glycolylneuraminic acid causes an immune response in humans. Heme iron, which is found in mammalian muscle tissue and egg yolk, has been associated with all-cause mortality. Cooking methods may also have an influence although this may affect other types of foods in addition to meat – high cooking temperatures can lead to the formation of carcinogenic polycyclic aromatic hydrocarbons, for example. The health risks associated with processed meat could be because of their relatively higher content of sodium, saturated fats and nitrates than unprocessed meat. Processed meats are also associated with carcinogenic compounds such as N-nitroso-compounds that can form during manufacturing. The consumption of white meat has not yet been associated with the same health consequences as the consumption of red meat, but this could be because fewer studies have been undertaken.

Human diseases that can be contracted from food may be caused by bacteria, viruses, protozoans, helminths, nematodes or chemicals. A common bacterial foodborne illness is *Campylobacter* spp., which is associated with infected poultry. Other common diseases are caused by *Salmonella* spp., which is found in poultry and eggs, and *Escherichia coli* O157, which is found in cattle and can be spread following contact with faeces of contaminated animals and in contaminated food. *Taenia solium* (pig tapeworm) and *Taenia saginata* (beef tapeworm) are examples of helminth parasites, which can be transferred to humans after consuming undercooked infected pork or beef.

In addition to the potential health impacts from eating meat, livestock production (particularly from intensive systems) can increase health risks to the wider population whether or not they are meat eaters. Chemical compounds used in farming – such as nitrates

"In addition to the potential health impacts from eating meat, livestock production can increase health risks to the wider population whether or not they are meat eaters"



The Sustainable School Lunch Program in Thailand is aimed at promoting kindergarten and primary school lunches that are safe, nutritious, and made from ecological ingredients which are healthy for both for the students and the environment

and phosphorus from fertiliser applications – can enter waterways and pollute drinking water supplies. The excessive use of antimicrobial compounds in livestock production as therapeutic agents, prophylactics or growth promoters has the potential to lead to the development of antimicrobial resistance in organisms and could significantly affect human health.

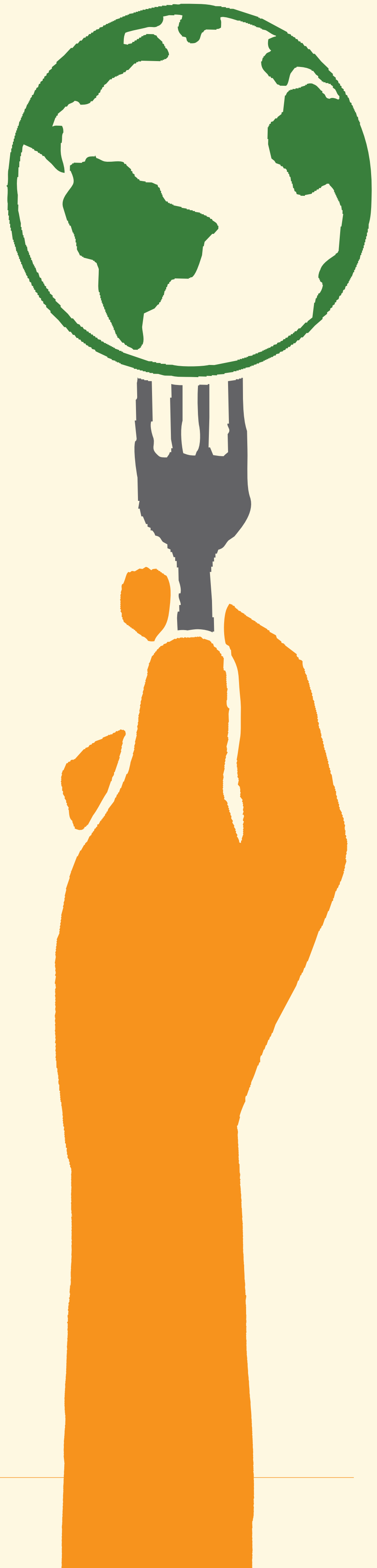
Other diseases that may be linked to livestock production systems include bladder, thyroid and gastric cancer, non-Hodgkin's lymphoma, and methaemoglobinaemia, also known as blue-baby syndrome. Fine dust particles, feathers and animal hair, microbes, gases and endotoxins can all be emitted from intensive farming operations and may lead to poor air quality in the surrounding area. Poor air quality can cause or exacerbate symptoms of diseases including asthma-like conditions, chronic obstructive pulmonary disease and pneumonia in local non-farming residents as well as among the farming community.

Nutritional studies have identified health benefits from plant-rich diets with reduced meat intake. A simple example of how to achieve this would be to replace one serving of meat with one serving of nuts, pulses, vegetables or fruit. Identified health benefits include reduced risk of developing non-communicable diseases such as type II diabetes, cancers and coronary heart disease, and an overall increased life expectancy.

Evidence suggests that some populations in industrialised nations are already reducing their consumption of meat. For example, one study found a decrease in the median consumption of red meat among women living in the USA in the 1980s and 1990s (Bernstein et al., 2010). Data were collected from 84,136 women enrolled in the Nurses' Health Study. Meat intake decreased from 1.06 servings per day in 1980 to 0.49 servings per day in 2002. Reasons for the change in meat consumption among the women in the study were not explored.

In affluent societies and rapidly developing economies, current trends are towards progressively increasing availability and consumption of meat and dairy products – largely because of the trend towards industrially produced livestock. Any general incidence on non-communicable disease is not only because of diet. Other factors are at play including lifestyle choices such as smoking, exercise and genetics. Factor in as well the long life span of many twenty-first century humans, and it becomes evident that the once beneficial effects from the occasional consumption of meat from wild animals are likely becoming eclipsed by multiple negative impacts of overconsumption of animal products.

What Greenpeace demands



This wide-ranging review of the scientific evidence on meat and dairy impacts on planetary health, the issue of animal production and consumption is highly complex and deeply interwoven with how we choose to live today. It can not be addressed effectively simply by isolating its different components, as each component is closely interlinked and interdependent. Reshaping our food system requires an integrated approach to the necessary societal and policy interventions. These interventions are multi-sectoral and multidisciplinary. We need to look at options for fine tuning demand and supply of food, agriculture and nutrition, farmers and consumers, as well as addressing the cultural differences for both high- and low-meat consuming countries.

The food revolution Greenpeace is calling for requires large-scale changes by governments, businesses and individuals. It will need integral changes in the food system from the farm to the home to phase out industrial meat and achieve the halving of production and consumption of meat and dairy by 2050, based on current levels.

Greenpeace is calling on politicians to:

1. End subsidies and policies that support industrial meat and dairy products, and adopt subsidies and policies that promote the production of healthy fruits and vegetables from ecological farms, as well as better meat and dairy from ecological livestock producers[1].

2. Adopt policies to cut public spending on industrial meat and dairy products while increasing economic support towards plant-rich options sourced from local ecological farmers, and replace remaining meat and dairy by goods produced by ecological farmers. In particular, urge public authorities to quickly adopt procurement policies for public canteens that support this model.

3. Adopt policies driving change in dietary habits and consumption patterns, including setting targets towards less meat and dairy.

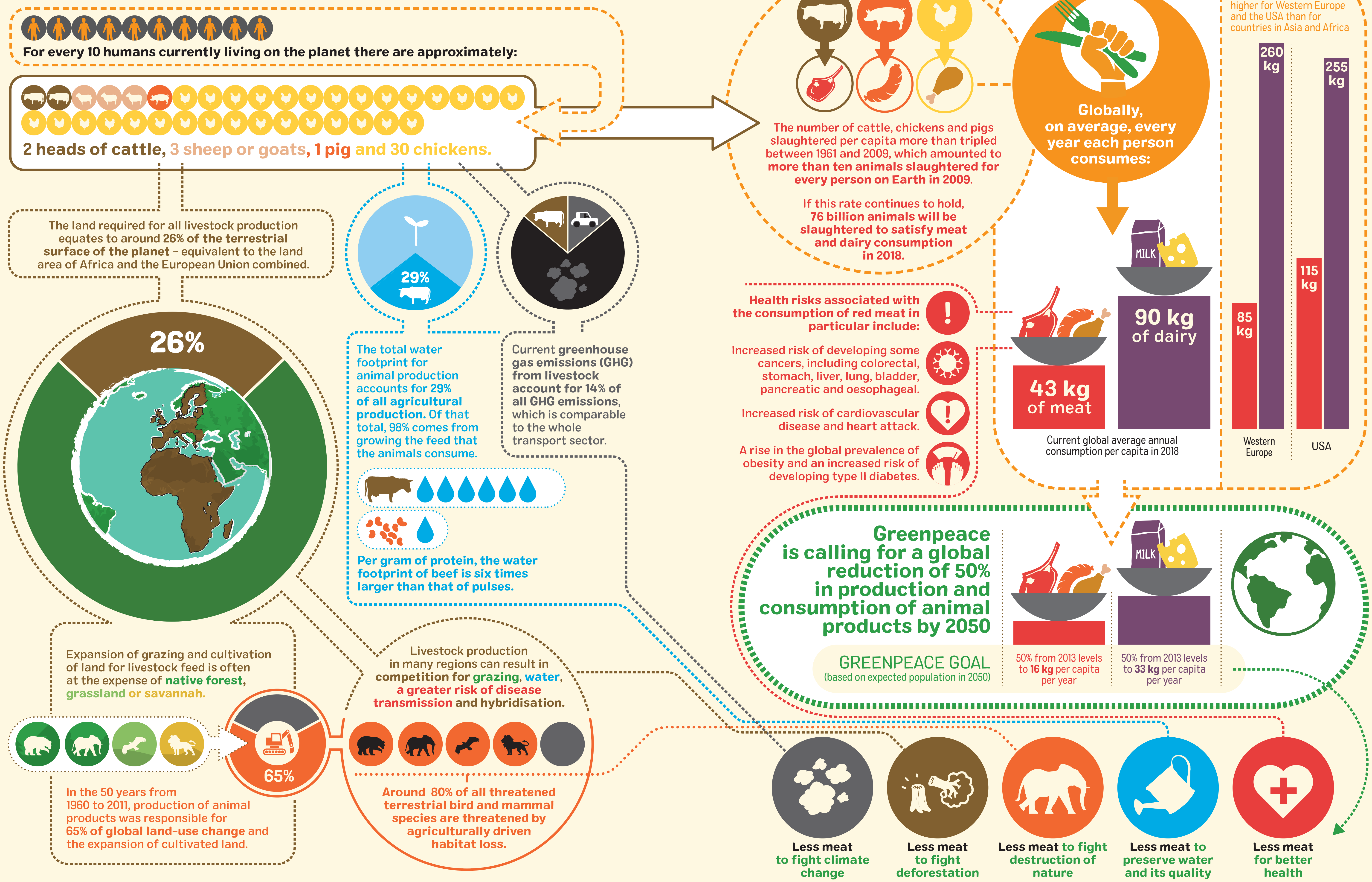
4. Involve decision-makers from the health and environmental sectors in the design of agricultural policies, due to the wider impacts of the livestock sector on human health and the environment.

Greenpeace is also calling on **business and corporations** to put planetary health over profit and publicly commit to a transition towards plant-based diets and ecological meat and dairy, by establishing a roadmap to fulfill the needed food-system transformation.

Lastly, Greenpeace is calling on all of us, from young people to seniors, to use our collective will and creativity to reimagine the way we eat.

1. Greenpeace's 'ecological livestock' criteria can be found in the Appendix page 78.

A child eats ecological food at school Escola de Educação Infantil São Pedro in the city of Guabiruba, state of Santa Catarina, Brazil


For every 10 humans currently living on the planet there are approximately:
2 heads of cattle, 3 sheep or goats, 1 pig and 30 chickens.
The land required for all livestock production equates to around 26% of the terrestrial surface of the planet – equivalent to the land area of Africa and the European Union combined.
26%
29%
The total water footprint for animal production accounts for 29% of all agricultural production. Of that total, 98% comes from growing the feed that the animals consume.
Current greenhouse gas emissions (GHG) from livestock account for 14% of all GHG emissions, which is comparable to the whole transport sector.
Per gram of protein, the water footprint of beef is six times larger than that of pulses.
Expansion of grazing and cultivation of land for livestock feed is often at the expense of native forest, grassland or savannah.
65%
In the 50 years from 1960 to 2011, production of animal products was responsible for 65% of global land-use change and the expansion of cultivated land.
Livestock production in many regions can result in competition for grazing, water, a greater risk of disease transmission and hybridisation.
Around 80% of all threatened terrestrial bird and mammal species are threatened by agriculturally driven habitat loss.
The number of cattle, chickens and pigs slaughtered per capita more than tripled between 1961 and 2009, which amounted to more than ten animals slaughtered for every person on Earth in 2009.
If this rate continues to hold, 76 billion animals will be slaughtered to satisfy meat and dairy consumption in 2018.
Globally, on average, every year each person consumes:
43 kg of meat
MILK
90 kg of dairy
Current global average annual consumption per capita in 2018
The figures are much higher for Western Europe and the USA than for countries in Asia and Africa
85 kg
260 kg
Western Europe
115 kg
255 kg
USA
Health risks associated with the consumption of red meat in particular include:
Increased risk of developing some cancers, including colorectal, stomach, liver, lung, bladder, pancreatic and oesophageal.
Increased risk of cardiovascular disease and heart attack.
A rise in the global prevalence of obesity and an increased risk of developing type II diabetes.
Greenpeace is calling for a global reduction of 50% in production and consumption of animal products by 2050
GREENPEACE GOAL
(based on expected population in 2050)
MILK
50% from 2013 levels to 16 kg per capita per year
50% from 2013 levels to 33 kg per capita per year
Less meat to fight climate change
Less meat to fight deforestation
Less meat to fight destruction of nature
Less meat to preserve water and its quality
Less meat for better health

References

A-M

A

Aarestrup, F. M. 2015. The livestock reservoir for antimicrobial resistance: a personal view on changing patterns of risks, effects of interventions and the way forward. Philosophical Transactions of the Royal Society B: Biological Sciences, 370: 20140085.

Abbaspour, N., Hurrell, R. & Kelishadi, R. 2014. Review on iron and its importance for human health. Journal of Research in Medical Sciences 19: 164–174.

Abete, I., et al. 2014. Association between total, processed, red and white meat consumption and all-cause, CVD and IHD mortality: A meta-analysis of cohort studies. British Journal of Nutrition 112: 762–775.

Aleksandrowicz, L., Green, R., Joy, E. J. M., Smith, P., & Haines, A. 2016. The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: A systematic review. PLoS ONE, 11: e0165797.

Alexander, P., et al. 2015. Drivers for global agricultural land use change: The nexus of diet, population, yield and bioenergy. Global Environmental Change, 35: 138–147.

Alexandratos, N. & Bruinsma, J. 2012. *World agriculture towards 2030/2050: the 2012 revision.* ESA Working Paper No. 12-03. Food and Agriculture Organisation of the United Nations: Rome. http://www.fao.org/docrep/016/ap106e/ap106e.pdf [Accessed February 5 2018].

Alisson-Silva, F., Kawanishi, K. & Varki, A. 2016. Human risk of diseases associated with red meat intake: Analysis of current theories and proposed role for metabolic incorporation of a non-human sialic acid. Molecular Aspects of Medicine, 51: 16–30.

Allievi, F., Vinnari, M. & Luukkanen, J. 2015. Meat consumption and production – analysis of efficiency, sufficiency and consistency of global trends. Journal of Cleaner Production, 92: 142-151.

Althor, G., Watson, J. E. M. & Fuller, R. A. 2016. Global mismatch between greenhouse gas emissions and the burden of climate change. Scientific Reports, 6: 20281.

Alvarado, F., Escobar, F., Williams, D. R., Arroyo-Rodríguez, V., & Escobar-Hernández, F. 2017. The role of livestock intensification and landscape structure in maintaining tropical biodiversity. Journal of Applied Ecology, 55: 185–194.

Appleby, PN, Thorogood, M, Mann, JI & Key, TJA. 1999. The Oxford Vegetarian Study: An overview. American Journal of Clinical Nutrition, 70: 525S–531S.

Arneth, A., et al. 2017. Historical carbon dioxide emissions caused by land-use changes are possibly larger than assumed. Nature Geoscience, 10: 79–84.

Ascott, M. J., et al. 2017. Global patterns of nitrate storage in the vadose zone. Nature Communications, 8: 1416.

A

Baccini, A., et al. 2015. Tropical forests are a net carbon source based on new measurements of gain and loss. Science, 5962: 1–11.

Bajželj, B., et al. 2014. Importance of food-demand management for climate mitigation. Nature Climate Change, 4: 924–929.

Barnosky, A. D., et al. 2011. Has the Earth's sixth mass extinction already arrived? Nature, 471: 51–57.

Batchelor, J. L., Ripple, W. J., Wilson, T. M., & Painter, L. E. 2015. Restoration of riparian areas following the removal of cattle in the northwestern Great Basin. Environmental Management, 55: 930–942.

Bebber, D. P., Butt, N. 2017. Tropical protected areas reduced deforestation carbon emissions by one third from 2000–2012. Scientific Reports, 7: 14005.

Bengtsson-Palme, J. 2017. Antibiotic resistance in the food supply chain: Where can sequencing and metagenomics aid risk assessment? Current Opinion in Food Science, 14: 66–71.

Bernstein, A. M., et al. 2010. Major dietary protein sources and the risk of coronary heart disease in women. Circulation, 122: 876–883.

Bertolini, L. R., et al. 2016. The transgenic animal platform for biopharmaceutical production. Transgenic Research, 25: 329–343.

Bett, B., et al. 2017. Effects of climate change on the occurrence and distribution of livestock diseases. Preventive Veterinary Medicine, 137: 119–129.

Bian, S. et al. (2018) Dairy product consumption and risk of hip fracture: a systematic review and meta-analysis. BMC Public Health. 18: 165.

Billen, G., Garnier, J., & Lassaletta, L. 2013. The nitrogen cascade from agricultural soils to the sea: modelling nitrogen transfers at regional watershed and global scales. Philosophical Transactions of the Royal Society of London Series B: Biological Sciences, 368: 20130123.

Bishop, S. C., & Woolliams, J. A. 2014. Genomics and disease resistance studies in livestock. Livestock Science, 166: 190–198.

Boada, L. D., Henríquez-Hernández, L. A. & Luzardo, O.P. 2016. The impact of red and processed meat consumption on cancer and other health outcomes: Epidemiological evidences. Food and Chemical Toxicology, 92: 236–244.

Bodirsky, B. L., et al. 2014. Reactive nitrogen requirements to feed the world in 2050 and potential to mitigate nitrogen pollution. Nature Communications, 5: 3858.

Boesing, A. L., Nichols, E., & Metzger, J. P. 2017. Biodiversity extinction thresholds are modulated by matrix type. Ecography, 41: 1–14.

Bolland, M. et al. 2015. Calcium intake and risk of fracture: systematic review. British Medical Journal, 351: h4580.

Bortolaia, V., Espinosa-Gongora, C., & Guardabassi, L. 2016. Human health risks associated with antimicrobial-resistant enterococci and *Staphylococcus aureus* on poultry meat. Clinical Microbiology and Infection, 22: 130–140.

Bouvard, V., et al. 2015. International Agency for Research on Cancer Monograph Working Group. Carcinogenicity of consumption of red and processed meat. Lancet Oncology, 16: 1599–1600.

Bouwman, A. F., Beusen, A. H. W., & Billen, G. 2009. Human alteration of the global nitrogen and phosphorus soil balances for the period 1970-2050. Global Biogeochemical Cycles, 23: GB0A04.

Bouwman, L., et al. 2013. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. Proceedings of the National Academy of Sciences, 110: 20882–20887.

C

Cai, L., et al. 2015. Multivariate and geostatistical analyses of the spatial distribution and source of arsenic and heavy metals in the agricultural soils in Shunde, Southeast China. Journal of Geochemical Exploration, 148: 189–195.

Campbell, B. M., et al. 2017. Agriculture production as a major driver of the earth system exceeding planetary boundaries. Ecology and Society, 22: 8.

Cao, C., et al. 2017. Meat intake and risk of diverticulitis among men. Gut Published Online First: 09 January 2017. doi: 10.1136/gutjnl-2016-313082.

Caruso, C. et al. 2017. Hepatitis E Virus: A cross-sectional serological and virological study in pigs and humans at zoonotic risk within a high-density pig farming area. Transboundary and Emerging Diseases, 64: 1443–1453.

Casey et al. 2013. High-density livestock operations, crop field application of manure, and risk of community-associated methicillin-resistant *Staphylococcus aureus* infection in Pennsylvania. JAMA Internal Medicine 173: 1980–1990.

Cassidy, E. S., West, P. C., Gerber, J. S., & Foley, J. A. 2013. Redefining agricultural yields: from tonnes to people nourished per hectare. Environmental Research Letters, 8: 34015.

Centers for Disease Control and Prevention. 2017. National Diabetes Statistics Report, 2017. Estimates of Diabetes and Its Burden in the United States. Centers for Disease Control and Prevention. https://www.cdc.gov/diabetes/pdfs/data/statistics/national-diabetes-statistics-report.pdf [Accessed October 24, 2017].

Chagnon, M., et al. 2015. Risks of large-scale use of systemic insecticides to ecosystem functioning and services. Environmental Science and Pollution Research, 22: 119–134.

Chen, G.-C. et al. 2017. Cheese consumption and risk of cardiovascular disease: a meta- analysis of prospective studies. European Journal of Nutrition, 56: 2565–2575.

Chen, M., et al. 2016. Dairy fat and risk of cardiovascular disease in 3 cohorts of US adults. American Journal of Clinical Nutrition, 104: 1209–1217.

Craig, W. J., & Mangels, A. R. 2009. Position of the American Dietetic Association: vegetarian diets. Journal of the American Dietetic Association, 109: 1266–82.

Crist, E., Mora, C., & Engelman, R. 2017. The interaction of human populations, food production and biodiversity protection. Science, 264: 260–264.

Cuny, C., Wieler, L.H., & Witte, W. 2015. Livestock associated MRSA: The impact on humans. Antibiotics (Basel) 4: 521-543.

D

DARC/ARHAI. 2012. Extended-spectrum beta (-)-lactamases (ESBLs): A threat to human and animal health? A report by the joint working group of the Defra Antimicrobial Resistance Coordination (DARC) Group and the Advisory Committee on Antimicrobial Resistance and Healthcare Associated Infection (ARHAI). February 2012. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/215180/dh_132534.pdf [Accessed on February 7 2018].

Dervilly-Pinel, G. et al. 2017. Micropollutants and chemical residues in organic and conventional meat. Food Chemistry 232: 218–228.

Diaz, R. J., & Rosenberg, R. 2008. Spreading dead zones and consequences for marine ecosystems. Science, 321: 926–929.

Diaz, R. J., & Rosenberg, R. 2011. Introduction to environmental and economic consequences of hypoxia. International Journal of Water Resources Development, 27: 71–82.

Dorrough, J., Moll, J., & Crosthwaite, J. 2007. Can intensification of temperate Australian livestock production systems save land for native biodiversity? Agriculture, Ecosystems and Environment, 121: 222–232.

Ducrotoy, M. J., et al. 2015. Narrative overview of animal and human brucellosis in Morocco: Intensification of livestock production as a driver for emergence? Infectious Diseases of Poverty, 4: 57.

Dumas, A.-A. et al. 2017. A systematic review of the effect of yogurt consumption on chronic diseases risk markers in adults. European Journal of Nutrition, 56: 1375–1392.

Dunlop, M. et al. 2013. Odour, dust and non-methane volatile organic-compound emissions from tunnel-ventilated layer-chicken sheds: a case study of two farms. Animal Production Science, 53: 1309–1318.

E

Eklund, A., López-Bao, J. V., Tourani, M., Chapron, G., & Frank, J. 2017. Limited evidence on the effectiveness of interventions to reduce livestock predation by large carnivores. Scientific Reports, 7: 1–9.

Eshel, G., Shepon, A., Makov, T., & Milo, R. 2014. Land, irrigation water, greenhouse gas, and reactive nitrogen burdens of meat, eggs, and dairy production in the United States. Proceedings of the National Academy of Sciences, 111: 11996–12001.

Etemadi, A., et al. 2017. Mortality from different causes associated with meat, heme iron, nitrates, and nitrites in the NIH-AARP Diet and Health Study: population based cohort study. British Medical Journal, 357: j1957.

European Commission. 2017. A European One Health Action Plan against Antimicrobial Resistance (AMR). 22 pp. https://ec.europa.eu/health/amr/sites/amr/files/amr_action_plan_2017_en.pdf [Accessed February 5 2018].

EEA. 2013. *Late lessons from early warnings: Science, precaution, innovation.* European Environment Agency. EEA Report No 1/2013. https://www.eea.europa.eu/publications/late-lessons-2 [Accessed February 5 2018].

Evans, D. M., et al. 2015. The cascading impacts of livestock grazing in upland ecosystems: a 10-year experiment. Ecosphere, 6: 1–15.

F

Fairlie, S. 2010. *Meat: A benign extravagance.* Permanent Publications, Hampshire, UK. 336 pp.

FAO. 2010a. *Status of and Prospects for Smallholder Milk Production – A Global Perspective*. Eds. Hemme, T. & Otte, J., Food and Agriculture Organisation of the United Nations: Rome. 12 pp. http://www.fao.org/docrep/012/i1522e/i1522e00.pdf [Accessed February 5 2018].

FAO. 2010b. *Fats and fatty acids in human nutrition. Report of an expert consultation.* Food and Agriculture Organisation of the United Nations: Rome. FAO Food and Nutrition Paper. Report No. 91. 166 pp. http://www.fao.org/3/a-i1953e.pdf [Accessed February 5 2018].

FAO. 2011. *Global food losses and food waste – Extent, causes and prevention.* Food and Agriculture Organisation of the United Nations: Rome. 29 pp. http://www.fao.org/docrep/014/mb060e/mb060e00.pdf [Accessed February 5 2018]. NOT IN TEXT

FAO. 2013. *Poultry and poultry products – risks for human health.* Food and Agriculture Organisation of the United Nations – Poultry Development Review: Rome. 3 pp. http://www.fao.org/3/a-al741e.pdf [Accessed February 5 2018].

FAO. 2014. Food and Agriculture Organization of the United Nations Regional Office for Europe and Central Asia. http://www.fao.org/3/a-i3621e [Accessed November 9. 2017].

Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North-America. Conservation Biology, 8: 629–644.

Feilberg, A., Hansen, M. J., Liu, D., & Nyord, T. 2017. Contribution of livestock H2S to total sulfur emissions in a region with intensive animal production. Nature Communications, 8: 1069.

Foley, J. A., et al. 2005. Global consequences of land use. Science, 309: 570–574.

Foley, J. A., et al. 2011. Solutions for a cultivated planet. Nature, 478: 337–342.

Freidl, G. S., et al. 2017. Livestock-associated risk factors for pneumonia in an area of intensive animal farming in the Netherlands. PLoS ONE, 12: e0174796.

G

Gakidou, E., et al. 2017. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990-2013; 2016: A systematic analysis for the Global Burden of Disease Study 2016. The Lancet, 390: 1345–1422.

Galloway, J. N., et al. 2007. International trade in meat: The tip of the pork chop. Ambio, 36: 622–629.

Gao, M, et al. 1999. Cardiovascular risk factors emerging in Chinese populations undergoing urbanization. Hypertension Research, 22: 209–215.

Garnett, T. 2009. Livestock-related greenhouse gas emissions: impacts and options for policy makers. Environmental Science and Policy, 12: 491–503.

Garnett, T., et al. 2017. *Grazed and confused? Ruminating on cattle, grazing systems, methane, nitrous oxide, the soil carbon sequestration question.* Food Climate Research Network, Oxford Martin Programme on the Future of Food Environmental Change Institute, University of Oxford. 127 pp. https://www.fcrn.org.uk/sites/default/files/project-files/fcrn_gnc_report.pdf [Accessed February 5 2018].

Gerbens-Leenes, P. W., Mekonnen, M. M., & Hoekstra, A. Y. 2013. The water footprint of poultry, pork and beef: A comparative study in different countries and production systems. Water Resources and Industry, 1–2: 25–36.

Gerten, D., et al. 2013. Towards a revised planetary boundary for consumptive freshwater use: Role of environmental flow requirements. Current Opinion in Environmental Sustainability, 5: 551–558.

Gerten, D., et al. 2015. Response to Comment on "Planetary boundaries: Guiding human development on a changing planet." Science, 348: 1217.

Gibbons, D., Morrissey, C., & Mineau, P. 2015. A review of the direct and indirect effects of neonicotinoids and fipronil on vertebrate wildlife. Environmental Science and Pollution Research, 22: 103–118.

Gilchrist, M., Winyard, P. G., & Benjamin, N. 2010. Dietary nitrate – Good or bad? Nitric Oxide 22: 104–109.

GLOPAN, 2016. Global Panel on Agriculture and Food Systems for Nutrition. 2016. Foresight report: Food systems and diets: Facing the challenges of the 21st century. London, UK. 132 pp. https://glopan.org/sites/default/files/ForesightReport.pdf [Accessed February 5 2018].

Gordon, L. J.et al. 2017. Rewiring food systems to enhance human health and biosphere stewardship. Environmental Research Letters, 12: 100201.

Gormley, F. J., Little, C. L., Rawal, N., & Gillespie I. A. 2011. A 17-year review of foodborne outbreaks: describing the continuing decline in England and Wales (1992–2008). Epidemiology and Infection 139: 688–699.

Gortazar, C., et al. 2015. The wild side of disease control at the wildlife-livestock-human interface: A review. Frontiers in Veterinary Science, 1: 1–12.

Grace, D., et al. 2017. Poor livestock keepers: ecosystem-poverty-health interactions. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 372: 20160166.

Grinsven, H. J. M. van, Spiertz, J. H. J., Westhoek, H. J., Bouwman, A. F., & Erisman, J. W. 2014. Nitrogen use and food production in European regions from a global perspective. Journal of Agricultural Science, 152: S9–S19.

Gu, B., Ju, X., Chang, J., Ge, Y., & Vitousek, P. M. 2015. Integrated reactive nitrogen budgets and future trends in China. Proceedings of the National Academy of Sciences, 112: 8792–8797.

Guo, L. B., & Gifford, R. M. 2002. Soil carbon stocks and land use change: A meta-analysis. Global Change Biology, 8: 345–360.

H

Hallmann, C. A., et al. 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLoS ONE, 12: e0185809.

Hedenus, F., Wirsenius, S. & Johansson, D. J. A. 2014. The importance of reduced meat and dairy consumption for meeting stringent climate change targets. Climatic Change, 124: 79-91.

Henchion, M., McCarthy, M., Resconi, V. C. & Troy, D. 2014. Meat consumption: Trends and quality matters. Meat Science, 98: 561-568.

Herrero, M., & Thornton, P. K. 2013. Livestock and global change: Emerging issues for sustainable food systems. Proceedings of the National Academy of Sciences, 110: 20878–20881.

Herrero, M., et al. 2016. Greenhouse gas mitigation potentials in the livestock sector. Nature Climate Change, 6: 452–461.

Hilker, T., Natsagdorj, E., Waring, R. H., Lyapustin, A., & Wang, Y. 2014. Satellite observed widespread decline in Mongolian grasslands largely due to overgrazing. Global Change Biology, 20: 418–428.

Hiltunen, T., Virta, M., & Laine, A.-L. 2017. Antibiotic resistance in the wild: An eco-evolutionary perspective. Philosophical Transactions of the Royal Society B: Biological Sciences, 372: 20160039.

Hoekstra, A. Y. 2012. The hidden water resource use behind meat and dairy. Animal Frontiers, 2: 3–8.

Hosonuma, N., et al. 2012. An assessment of deforestation and forest degradation drivers in developing countries. Environmental Research Letters, 7: 044009.

Huerta, A. R., Güereca, L. P., & Lozano, M. D. 2016. Environmental impact of beef production in Mexico through life cycle assessment. Resources, Conservation and Recycling, 109: 44–53.

Hunt, A, Harrington, D., & Robinson, S. 2014. Vitamin B12 deficiency. British Medical Journal 349: g5226.

I

IARC. 2010. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 94. Ingested nitrate and nitrite, and cyanobacterial peptide toxins. Lyon: International Agency for Research on Cancer. http://monographs.iarc.fr/ENG/Monographs/vol94/mono94.pdf [Accessed November 9 2018].

IARC. 2015. IARC Monographs evaluate consumption of red meat and processed meat. International Agency for Research on Cancer. Press release No. 240. World Health Organisation (2015 https://www.iarc.fr/en/media-centre/pr/2015/pdfs/pr240_E.pdf [Accessed November 9 2017].

J

Jaramillo, F., & Destouni, G. 2015. Planetary boundaries: Guiding human development on a changing planet. Science, 9: 348.

Joppa, L. N. et al. 2016. Filling biodiversity threat gaps. Science, 352: 416–418.

K

Kaluza J., Wolk, A., & Larsson, S. C. 2012. Red meat consumption and risk of stroke: a meta-analysis of prospective studies. Stroke, 43: 2556–60.

Kastner, T., Rivas, M. J. I., Koch, W., & Nonhebel, S. 2012. Global changes in diets and the consequences for land requirements for food. Proceedings of the National Academy of Sciences, 109: 6868–6872.

Kauffman, J. B., Krueger, W. C., & Vavra, M. 1983. Impacts of cattle on streambanks in north-eastern Oregon. Journal of Range Management, 36: 683–685.

Kearney, J. 2010. Food consumption trends and drivers. Philosophical Transactions of the Royal Society B: Biological Sciences, 365: 2793.

Kissinger, G., Herold, M., & De Sy, V. 2012. Drivers of deforestation and forest degradation. *A Synthesis Report for REDD+ Policymakers*. 48 pp. https://doi.org/10.1016/j.rse.2010.01.001 [Accessed February 5 2018].

Knapp, R. A., & Matthews, K. R. 1996. Livestock grazing, golden trout, and streams in the golden trout wilderness, California: Impacts and management implications. North American Journal of Fisheries, 16: 805–820.

Koch, B., Hungate, B. A., & Price, L. B. 2017. Food-animal production and the spread of antibiotic resistance: the role of ecology. Frontiers Ecology and Environment, 15: 309–318.

Koo, L. C., Mang, O. W. K., & Ho, J. H.-C. 1997. An ecological study of trends in cancer incidence and dietary changes in Hong Kong. Nutrition and Cancer, 28: 289–301.

Kristensen, T. N., Hoffmann, A. A., Pertoldi, C., & Stronen, A. V. 2015. What can livestock breeders learn from conservation genetics and vice versa? Frontiers in Genetics, 5: 1–12.

L

Lamas-Toranzo, I., et al. 2017. CRISPR is knocking on barn door. Reproduction in Domestic Animals, 52: 39–47.

Larsson, S. C., & Orsini, N. 2014. Red meat and processed meat consumption and all-cause mortality: a meta-analysis. American Journal of Epidemiology, 357: 282–289.

Le Bouquin, S., et al. 2013. Aerial dust concentration in cage-housed, floor-housed, and aviary facilities for laying hens. Poultry Science, 92: 2827–2833.

Lean, M. E. J. et al. 2017. Primary care-led weight management for remission of type 2 diabetes (DiRECT): an open-label, cluster-randomised trial. *Lancet* Published online December 5 2017.

Ledford, H. 2016. Riding the CRISPR wave. Nature, 531: 156–159.

Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., & Pozzer, A. 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature, 525: 367–371.

Lesser, L.I., Ebbeling, C.B., Goozner, M., Wypij, D., & Ludwig, D.S. 2007. Relationship between funding source and conclusion among nutrition-related scientific articles. PLoS Medicine 4: e5.

Lippi, G., Mattiuzzi, C., & Cervellin, G. 2016. Meat consumption and cancer risk: a critical review of published meta-analyses. Critical Reviews in Oncology and Hematology, 97: 1–14.

Loftus, C. et al. 2015. Ambient ammonia exposures in an agricultural community and pediatric asthma morbidity. Epidemiology, 26: 794–801.

Lovegrove, J. A., & Hobbs, D. A. 2016. New perspectives on dairy and cardiovascular health. Proceedings of the Nutritional Society, 75, 247–258.

Lovegrove, J. A., Stainer, A., & Hobbs, D. A. 2017. Role of flavonoids and nitrates in cardiovascular health. Proceedings of the Nutritional Society, 76: 83–95.

Lu, L. Xun, P., Wan, Y., He, K., & Cai, W. 2016. Long-term association between dairy consumption and risk of childhood obesity: a systematic review and meta-analysis of prospective cohort studies. European Journal of Clinical Nutrition, 70: 414–423.

M

Machovina, B., & Feeley, K. J. 2014. Meat consumption as a key impact on tropical nature: A response to Laurance et al. Trends in Ecology and Evolution, 29: 430–431.

Machovina, B., Feeley, K. J., & Ripple, W. J. 2015. Biodiversity conservation: The key is reducing meat consumption. Science of the Total Environment, 536: 419–431.

Malik, V. S., Willett, W. C. & Hu, F. B. 2012. Global obesity: trends, risk factors and policy implications. Nature Reviews Endocrinology, 9: 13.

Mallin, M. A., McIver, M. R., Robuck, A. R., & Dickens, A. K. 2015. Industrial swine and poultry production causes chronic nutrient and fecal microbial stream pollution. Water, Air and Soil Pollution, 227: 407.

Mallon, D. P., & Zhigang, J. 2009. Grazers on the plains: Challenges and prospects for large herbivores in Central Asia. Journal of Applied Ecology, 46: 516–519.

Marshall, B. M., & Levy, S. B. 2011. Food animals and antimicrobials: impacts on human health. Clinical Microbiology Reviews, 24: 718–733.

McKnight, G. M., Duncan, C. W., Leifert, C., & Golden, M. H. 1999. Dietary nitrate in man: Friend or foe? British Journal of Nutrition, 81: 349–358.

Mekonnen, M. M., & Hoekstra, A. Y. 2012. A global assessment of the water footprint of farm animal products. Ecosystems, 15: 401–415.

Metson, G. S., Bennett, E. M., & Elser, J. J. 2012. The role of diet in phosphorus demand. Environmental Research Letters, 7: 44043.

Metson, G. S., et al. 2014. Phosphorus is a key component of the resource demands for meat, eggs, and dairy production in the United States. Proceedings of the National Academy of Sciences, 111: E4906–E4907.

Michaëlsson, K. et al. 2014. Milk intake and risk of mortality and fractures in women and men: Cohort studies. British Medical Journal, 349: g6015.

References

M–Z

Miller, V. et al. 2017. Fruit, vegetable, and legume intake, and cardiovascular disease and deaths in 18 countries (PURE): A prospective cohort study. Lancet, 390: 2037–2049.

Morrissey, C. A., et al. 2015. Neonicotinoid contamination of global surface waters and associated risk to aquatic invertebrates: A review. Environment International, 74: 291–303.

Mottet, A., et al. 2017. Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. Global Food Security, 14: 1–8.

Muller, A., et al. 2017. Strategies for feeding the world more sustainably with organic agriculture. Nature Communications, 8: 1290.

N

Narvaez-Bravo, C. et al. 2016. Prevalence of methicillin-resistant *Staphylococcus aureus* in Canadian commercial pork processing plants. Journal of Applied Microbiology, 120:770–780.

Nguyen, T. L. T., Hermansen, J. E., & Mogensen, L. 2012. Environmental costs of meat production: The case of typical EU pork production. Journal of Cleaner Production, 28: 168–176.

NHS. 2015. UK National Health Service. Choices. Creutzfeldt Jakob disease. Available online at: https://www.nhs.uk/conditions/creutzfeldt-jakob-disease-cjd [Accessed November 14, 2017.]

NHS. 2016. UK National Health Service. Choices. Overview: Cardiovascular disease. Available online at: https://www.nhs.uk/Conditions/cardiovascular-disease/Pages/Introduction.aspx#types [Accessed October 25 2017.]

O

O'Neill, J. 2015. Antimicrobials in agriculture and the environment: Reducing unnecessary use and waste. Wellcome Trust & H.M. Government. 40 pp. https://ec.europa.eu/health/amr/sites/amr/files/amr_studies_2015_am-in-agri-and-env.pdf [Accessed February 6 2018].

O'Neill, J. 2016. Review on antimicrobial resistance: Tackling drug resistant infections globally - Final report and recommendations. Wellcome Trust & HM Government UK. 84 pp. https://amr-review.org/sites/default/files/160518_Final%20paper_with%20cover.pdf [Accessed February 6 2018].

Ockenden, M. C., et al. 2017. Major agricultural changes required to mitigate phosphorus losses under climate change. Nature Communications, 8: 161.

Oita, A., et al. 2016. Substantial nitrogen pollution embedded in international trade. Nature Geoscience, 9: 111–115.

Otto, M. C. et al (2012). Dietary intake of saturated fat by food source and incident cardiovascular disease: The multi-ethnic study of atherosclerosis. The American Journal of Clinical Nutrition, 96: 397–404.

Oxfam. 2015. Lives on the line: The human cost of cheap chicken. Oxfam America. https://www.oxfamamerica.org/static/media/files/Lives_on_the_Line_Full_Report_Final.pdf [Accessed February 6 2018].

Oxfam. 2016. Unearthed: Land, power and inequality. Oxfam International. https://www.oxfam.org/sites/www.oxfam.org/files/file_attachments/bp-land-power-inequality-latin-america-301116-en.pdf [Accessed February 6 2018].

P

Pan, Y., et al. 2011a. A large and persistent carbon sink in the world's forests. Science, 333: 988–993.

Pan, A., et al. 2011b. Red meat consumption and risk of type 2 diabetes: 3 cohorts of US adults and an updated meta-analysis. American Journal of Clinical Nutrition, 94: 1088–1096.

Pan, A., et al. 2012. Red meat consumption and mortality: Results from two prospective cohort studies. Archives of Internal Medicine, 357: 555–563.

Patel, H., Chandra, S., Alexander, S., Soble, J., & Williams Sr, K. A. 2017. Plant-based nutrition: An essential component of cardiovascular disease prevention and management. Current Cardiology Reports, 19: 104.

Paulot, F., & Jacob, D. J. 2013. Hidden cost of U.S. agricultural exports: Particulate matter from ammonia emissions. Environmental Science and Technology, 48: 903–908.

Pereira, M. A. et al. 2002. Dairy consumption, obesity, and the insulin resistance syndrome in Young Adults: The CARDIA Study. Journal of the American Medical Association, 287: 2081–2089.

Pereira, R., Simmons, C., & Walker, R. 2016. Smallholders, agrarian reform, and globalization in the Brazilian Amazon: Cattle versus the environment. Land, 5: 24.

Perry, B. D., Grace, D., & Sones, K. 2013. Current drivers and future directions of global livestock disease dynamics. Proceedings of the National Academy of Sciences, 110: 20871–20877.

Petersen, B. 2017. Basics of genome editing technology and its application in livestock species. Reproduction in Domestic Animals, 52: 4–13.

Piazza, J. et al. 2015. Rationalizing meat consumption. The 4Ns. Appetite, 91: 114–28.

Popp, A., Lotze-Campen, H. & Bodirsky, B. 2010. Food consumption, diet shifts and associated non-CO_2 greenhouse gases from agricultural production. Global Environmental Change, 20: 451-462.

Proudfoot, C., et al. 2015. Genome edited sheep and cattle. Transgenic Research, 24: 147–153.

Prudêncio da Silva, V., van der Werf, H. M. G., Soares, S. R., & Corson, M. S. 2014. Environmental impacts of French and Brazilian broiler chicken production scenarios: An LCA approach. Journal of Environmental Management, 133: 222–231.

Public Health England. 2013. List zoonotic diseases. https://www.gov.uk/government/publications/list-of-zoonotic-diseases/list-of-zoonotic-diseases [Accessed February 6 2018].

Public Health England. 2016. PHE Bulletin 29 September 2016. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/556910/PHE_Bulletin_September_2016.pdf. [Accessed October 24, 2017).

Public Health England. 2017. Zoonoses Overview Report UK 2016. 50 pp. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/664448/UK_Zoonoses_report_2016.pdf [Accessed February 6 2018].

Q

Quijano, L., et al. 2017. Risk assessment and monitoring programme of nitrates through vegetables in the Region of Valencia (Spain). Food and Chemical Toxicology, 100:42-49.

Quinteiro, P., Dias, A. C., Silva, M., Ridoutt, B. G., & Arroja, L. 2015. A contribution to the environmental impact assessment of green water flows. Journal of Cleaner Production, 93: 318–329.

R

Radon, K., et al. 2007. Environmental exposure to confined animal feeding operations and respiratory health of neighboring residents. Epidemiology, 18: 300-308.

Ran, Y., Lannerstad, M., Herrero, M., Van Middelaar, C. E., & De Boer, I. J. M. 2016. Assessing water resource use in livestock production: A review of methods. Livestock Science, 187: 68–79.

Ran, Y., van Middelaar, C. E., Lannerstad, M., Herrero, M., & De Boer, I. J. M. 2017. Freshwater use in livestock production — To be used for food crops or livestock feed? Agricultural Systems, 155: 1–8.

Read, C. F., Duncan, D. H., Vesk, P. A., & Elith, J. 2011. Surprisingly fast recovery of biological soil crusts following livestock removal in southern Australia. Journal of Vegetation Science, 22: 905–916.

Ripple, W. J., et al. 2014a. Status and ecological effects of the world's largest carnivores. Science, 343: 1241484–1241484.

Ripple, W. J., et al. 2014b. Ruminants, climate change and climate policy. Nature Climate Change, 4: 2–5.

Ripple, W. J., et al. 2015. Collapse of the world 's largest herbivores. Science Advances, (MAY): e1400103.

Ripple, W. J., et al. 2017. World scientists' warning to humanity: A second notice. BioScience, 67: 1026–1028.

Robinson, T. P., et al. 2014. Mapping the global distribution of livestock. PLoS ONE, 9: e96084.

Rockström, J., et al. 2009. A safe operating space for humanity. Nature, 461: 472–475.

Rogelj, J., et al. 2016. Paris Agreement climate proposals need a boost to keep warming well below 2 °C. Nature, 534: 631-639.

Rohrmann, S., et al. 2013. Meat consumption and mortality-results from the European prospective investigation into cancer and nutrition. BMC Medicine, 357: 63.

Röös, E., Patel, M., Spångberg, J., Carlsson, G. & Rydhmer, L. 2016. Limiting livestock production to pasture and by-products in a search for sustainable diets. Food Policy, 58: 1-13.

Röös, E., et al. 2017. Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures. Global Environmental Change, 47: 1-12.

Rose, D. P., Boyer, A. P., & Wynder, E. L. 1986. International comparisons of mortality rates for cancer of the breast, ovary, prostate, and colon, and per capita food consumption. Cancer, 58: 2363–2371.

Rouhani, M., Salehi-Abargouei, A., Surkan, P., & Azadbakht, L. 2014. Is there a relationship between red or processed meat intake and obesity? A systematic review and meta-analysis of observational studies. Obesity Reviews, 15: 740–748.

Ruan, J., Xu, J., Chen-Tsai, R. Y., & Li, K. 2017. Genome editing in livestock: Are we ready for a revolution in animal breeding industry? Transgenic Research, 26: 715–726.

S

Sadeghi, M. et al. 2014. Cheese consumption in relation to cardiovascular risk factors among Iranian adults: IHHP Study. Nutrition Research and Practice, 8: 336–341.

Salemdeeb, R., zu Ermgassen, E. K., Kim, M. H., Balmford, A., & Al-Tabbaa, A. 2017. Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. Journal of Cleaner Production, 140: 871–880.

Samraj, A. N. et al. 2015. A red meat-derived glycan promotes inflammation and cancer progression. Proceedings of the National Academy of Sciences, 112: 542–547.

Santamaria, P. 2005. Nitrate in vegetables: toxicity, content, intake and EC regulation. Journal of the Science of Food and Agriculture, 86: 10–17.

Sausenthaler, S. et al. 2006. Margarine and butter consumption, eczema and allergic sensitization in children. The LISA birth cohort study. Pediatric Allergy and Immunology, 17: 85–93.

Schader, C., et al. 2015. Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. Journal of The Royal Society Interface, 12: 20150891.

Seddon, N., et al. 2016. Biodiversity in the Anthropocene: prospects and policy. Proceedings of the Royal Society B: Biological Sciences, 283: 20162094.

Sengeløv, G., et al. 2003. Bacterial antibiotic resistance levels in Danish farmland as a result of treatment with pig manure slurry. Environment International, 28: 587–95.

Seves, S. M., Verkaik-Kloosterman, J., Biesbroek, S., & Temme, E. 2017. Are more environmentally sustainable diets with less meat and dairy nutritionally adequate? Public Health Nutrition, 20: 2050–2062.

Sharma, S. & Schlesinger, S. 2017. The Rise of Big Meat: Brazil's Extractive Industry. Institute for Agriculture and Trade Policy (IATP) November 2017. www.iatp.org/the-rise-of-big-meat [Accessed February 6 2018].

Shepon, A., Eshel, G., Noor, E. & Milo, R. 2016. Energy and protein feed-to-food conversion efficiencies in the US and potential food security gains from dietary changes. Environmental Research Letters, 11: 105002.

Singh, P. N., Sabate, J., Fraser, G. E. 2003. Does low meat consumption increase life expectancy in humans? American Journal of Clinical Nutrition, 78: 526S–32S.

Singh, B. B., Dhand, N. K., Ghatak, S., & Gill, J. P. S. 2014. Economic losses due to cystic echinococcosis in India: Need for urgent action to control the disease. Preventive Veterinary Medicine, 113: 1–12.

Sinha, R., Cross, A. J., Graubard, B. I., Leitzmann, M. F. &, Schatzkin, A. 2009. Meat intake and mortality: a prospective study of over half a million people. Archives of Internal Medicine, 169: 562 –571.

Sloan, S., & Sayer, J. A. 2015. Forest Resources Assessment of 2015 shows positive global trends but forest loss and degradation persist in poor tropical countries. Forest Ecology and Management, 352: 134–145.

Smit, L. A. M., Heederik, D. 2017. Impacts of intensive livestock production on human health in densely populated regions. GeoHealth, 7: 272–277.

Smith, R., & Coast, J. 2013. The true cost of antimicrobial resistance. British Medical Journal, 346: f1493.

Smith, P., et al. 2014. *Agriculture, Forestry and Other Land Use (AFOLU).* In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Eds. Edenhofer, O., et al. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Sobota, D. J., Compton, J. E., McCrackin, M. L., & Singh, S. 2015. Cost of reactive nitrogen release from human activities to the environment in the United States. Environmental Research Letters, 10: 0250006.

Song, M., et al. 2016. Association of animal and plant protein intake with all-cause and cause-specific mortality. JAMA Internal Medicine, 176: 1453.

Springmann, M., Godfray, H. C. J., Rayner, M. & Scarborough, P. 2016a. Analysis and valuation of the health and climate change cobenefits of dietary change. Proceedings of the National Academy of Sciences, 113: 4146–4151.

Springmann, M., et al. 2016b. Global and regional health effects of future food production under climate change: a modelling study. The Lancet, 387: 1937-1946.

Stanton, R. L., Morrissey, C. A., & Clark, R. G. 2018. Analysis of trends and agricultural drivers of farmland bird declines in North America: A review. Agriculture, Ecosystems & Environment, 254: 244–254.

Steffen, W., et al. 2015. Planetary boundaries: Guiding human development on a changing planet. Science, 348: 1259855.

Stehfest, E., et al. 2009. Climate benefits of changing diet. Climatic Change, 95: 83–102.

Stehle, S., & Schulz, R. 2015. Agricultural insecticides threaten surface waters at the global scale. Proceedings of the National Academy of Sciences, 112: 5750–5755.

Steinfeld, H. et al. 2006. *Livestock's long shadow - environmental issues and options.* Food and Agriculture Organization of the United Nations. 377 pp. https://doi.org/10.1007/s10666-008-9149-3 [Accessed February 6 2018].

Stoll-Kleemann, S., & O'Riordan, T. 2015. The Sustainability Challenges of Our Meat and Dairy Diets. Environment: Science and Policy for Sustainable Development, 57: 34–48.

Stoll-Kleemann, S., & Schmidt, U. J. 2017. Reducing meat consumption in developed and transition countries to counter climate change and biodiversity loss: a review of influence factors. Regional Environmental Change, 17: 1261–1277.

Suchy, F. J, et al. 2010. National Institute of Health consensus development conference: lactose intolerance in health. Annals of Internal Medicine, 152: 792–796.

Suryawanshi, K. R., et al. 2017. Impact of wild prey availability on livestock predation by snow leopards. Royal Society Open Science, 4: 170026.

Sutherland, W. J., et al. 2017. A 2018 horizon scan of emerging issues for global conservation and biological diversity. Trends in Ecology & Evolution, 33: 47–58.

Sutton, M. A., et al. 2011. Too much of a good thing. Nature, 472: 159–161.

Sutton, M. A., et al. 2013. *Our Nutrient World: The challenge to produce more food and energy with less pollution.* Edinburgh, NERC/Centre for Ecology & Hydrology, 114 pp. http://nora.nerc.ac.uk/id/eprint/500700/ [Accessed February 6 2018].

Swain, M., Blomqvist, L., McNamara, J., & Ripple, W. 2018. Reducing the environmental impact of global diets. Science of the Total Environment, 610–611: 1207–1209.

Świątkiewicz, S., Świątkiewicz, M., Arczewska-Włosek, A., & Józefiak, D. 2015. The use of genetic engineering techniques to improve the lipid composition in meat, milk and fish products: a review. Animal, 9: 696–706.

Szilagyi, A., Galiatsatos, P. & Xue X. 2016. Systematic review and meta-analysis of lactose digestion, its impact on intolerance and nutritional effects of dairy food restriction in inflammatory bowel diseases. Nutrition Journal, 15: 67.

T

Talaei, M., Koh, W.-P., Yuan, J.-M., & Pan, A. 2017. The association between dairy product intake and cardiovascular disease mortality in Chinese adults. European Journal of Nutrition, 56: 2343–2352.

Tantamango-Bartley, Y., et al. 2017. Independent associations of dairy and calcium intakes with colorectal cancers in the Adventist Health Study-2 cohort. Public Health Nutrition, 20: 2577–2586.

Taylor, D. M. 1986. Range management effects of cattle grazing on passerine birds nesting in riparian habitats. Journal of Range Management, 39: 254–258.

Thirgood, S., Woodroffe, R., & Rabinowitz, A. 2005. *The impact of human – wildlife conflict on natural systems.* In: People and Wildlife: Conflict or Coexistence? eds. Woodroffe, R., Thirgood, S. & Rabinowitz, A. Published by Cambridge University Press. pp 13–26.

Thow, A. M., Reeve, E., Naseri, T., Martyn, T., & Bollars, C. 2017. Food supply, nutrition and trade policy: reversal of an import ban on turkey tails. Bulletin of the World Health Organisation, 95: 723– 725.

Thronson, A., & Quigg, A. 2008. Fifty-five years of fish kills in coastal Texas. Estuaries and Coasts, 31: 802–813.

Tilman, D. & Clark, M. 2014. Global diets link environmental sustainability and human health. Nature, 515: 518.

Tilman, D., et al. 2017. Future threats to biodiversity and pathways to their prevention. Nature, 546: 73–81.

Tirado, R. & Kruszewska, I. 2012. Ecological Livestock: Options for reducing livestock production and consumption to fit within ecological limits, with a focus on Europe. Greenpeace Research Laboratories Technical Report (Review) 03-2012: 36 pp. http://www.greenpeace.org/international/en/publications/Campaign-reports/Agriculture/Ecological-Livestock/.

Tirado, R. 2015. Ecological Farming: The seven principles of a food system that has people at its heart. Eds. Baker, M., Kramb, D. Greenpeace International. 68 pp. http://www.greenpeace.to/greenpeace/wp-content/uploads/2015/05/Food-and-Farming-Vision.pdf [Accessed February 6 2018].

Tomley, F.M., & Shirley, M.W. 2009. Livestock infectious diseases and zoonoses. Philosophical Transactions of the Royal Society B: Biological Sciences, 364: 2637–2622.

Trewby, I. D., et al. 2008. Experimental evidence of competitive release in sympatric carnivores. Biology Letters, 4: 170–172.

Tscharntke, T., et al. 2012. Global food security, biodiversity conservation and the future of agricultural intensification. Biological Conservation, 151: 53–59.

V

Van Boeckel, T. P., et al. 2015. Global trends in antimicrobial use in food animals. Proceedings of the National Academy of Sciences, 112: 5649–5654.

Van Boeckel, T. P. et al. 2017. Reducing antimicrobial use in food animals. Science, 357: 1350–1352.

van Dijk, C et al. 2016. Risk of exacerbations in COPD and asthma patients living in the neighbourhood of livestock farms: Observational study using longitudinal data. International Journal of Hygiene and Environmental Health, 219: 278–287.

van Eeden, L. M., et al. 2017. Managing conflict between large carnivores and livestock. Conservation Biology, 32: 26–34.

Varki, A. 2010. Uniquely human evolution of sialic acid genetics and biology. Proceedings of the National Academy of Sciences, 107: 8939–8946.

Verones, F., et al. 2013. Effects of consumptive water use on biodiversity in wetlands of international importance. Environmental Science and Technology, 47: 12248–12257.

W

Wanders, A. J. et al. 2017. Fatty acid intake and its dietary sources in relation with markers of type 2 diabetes risk: The NEO study. European Journal of Clinical Nutrition, 71: 245–251.

Wang, X., et al. 2016. Red and processed meat consumption and mortality: dose-response meta-analysis of prospective cohort studies. Public Health Nutrition, 19: 893–905.

Wang, D., Campos, H., & Baylin, A. 2017. Red meat intake is positively associated with non-fatal acute myocardial infarction in the Costa Rica Heart Study. British Journal of Nutrition, 118: 303–311.

WCRF/AICR. 2007. World Cancer Research Fund / American Institute for Cancer Research. Food, nutrition, physical activity, and the prevention of cancer: A global perspective. Washington, DC: AICR, 2007. http://www.wcrf.org/sites/default/files/Second-Expert-Report.pdf [Accessed November 13, 2017].

WCRF. 2017. World Cancer Research Fund International/American Institute for Cancer Research. Continuous Update Project: Diet, nutrition, physical activity and the prevention of cancer. Summary of strong evidence. https://www.wcrf.org/sites/default/files/CUP_Matrix%20for%20all%20cancers_SEPT17_web.pdf [Accessed November 13, 2017].

Wei, H., et al. 2016. Whole-grain consumption and the risk of all-cause, CVD and cancer mortality: a meta-analysis of prospective cohort studies. British Journal of Nutrition, 116: 514–25.

Weindl, I., et al. 2017. Livestock production and the water challenge of future food supply: implications of agricultural management and dietary choices. Global Environmental Change, 47: 121–132.

Wepking, C., et al. 2017. Exposure to dairy manure leads to greater antibiotic resistance and increased mass-specific respiration in soil microbial communities. Proceedings of the Royal Society B: Biological Sciences, 284: 20162233.

Westhoek, H., et al. 2011. *The Protein Puzzle*. PBL Netherlands Environmental Assessment Agency. ISBN: 978-90-78645-61-0. www.pbl.nl/en [Accessed February 2 2018].

Westhoek, H., et al. 2014. Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. Global Environmental Change, 26: 196–205.

Whitelaw, C. B. A., Joshi, A., Kumar, S., Lillico, S. G., & Proudfoot, C. 2016. Genetically engineering milk. Journal of Dairy Research, 83: 3–11.

WHO. 2011. Nitrate and nitrite in drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality. World Health Organisation of the United Nations: Geneva. 31 pp. http://www.who.int/water_sanitation_health/dwq/chemicals/nitratenitrite2ndadd.pdf [Accessed February 6 2018].

WHO. 2015a. WHO estimates of the global burden of foodborne diseases. Foodborne diseases burden epidemiology reference group 2007-2015. World Health Organisation of the United Nations: Geneva. 255 pp. http://www.who.int/foodsafety/publications/foodborne_disease/fergreport/en [Accessed November 7, 2017].

WHO. 2015b. Healthy diet fact sheet No. 394. World Health Organisation of the United Nations: Geneva. http://www.who.int/mediacentre/factsheets/fs394/en/ [Accessed October 16, 2017.]

WHO. 2017a. WHO. Diabetes fact sheet. World Health Organisation of the United Nations: Geneva. 88 pp. www.who.int/diabetes/global-report/en/ [Accessed December 21, 2017.]

WHO. 2017b. WHO guidelines on use of medically important antimicrobials in food-producing animals. World Health Organization of the United Nations: Geneva. Licence: CC BY-NC-SA 3.0 IGO 88 pp. http://www.who.int/foodsafety/areas_work/antimicrobial-resistance/cia_guidelines/en/ [Accessed February 6 2018].

Wiethoelter, A. K., Beltrán-Alcrudo, D., Kock, R., & Mor, S. M. 2015. Global trends in infectious diseases at the wildlife–livestock interface. Proceedings of the National Academy of Sciences, 112: 9662–9667.

Wirsenius, S., Azar, C., & Berndes, G. 2010. How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? Agricultural Systems, 103: 621–638.

Wolf, C., & Ripple, W. J. 2016. Prey depletion as a threat to the world 's large carnivores. Royal Society Open Science, 3: 160252.

Wolf, C., & Ripple, W. J. 2017. Range contractions of the world's large carnivores. Royal Society Open Science, 4: 170052.

Wolk, A. 2016. Potential health hazards of eating red meat. Journal of Internal Medicine, 281: 106–122.

Woolhouse, M., Ward, M., van Bunnik, B., & Farrar, J. 2015. Antimicrobial resistance in humans, livestock and the wider environment. Philosophical Transactions of the Royal Society B: Biological Sciences, 370: 20140083.

Würtz, A. M. L. et al. 2016. Substitution of meat and fish with vegetables or potatoes and risk of myocardial infarction. British Journal of Nutrition, 116: 1602-1610.

Y

Yu, Y., Feng, K., & Hubacek, K. 2013. Tele-connecting local consumption to global land use. Global Environmental Change, 23: 1178–1186.

Z

Zhu, Y.-G., et al. 2013. Diverse and abundant antibiotic resistance genes in Chinese swine farms. Proceedings of the National Academy of Sciences, 110: 3435–3440.

Zonderland-Thomassen, M. A., Lieffering, M., & Ledgard, S. F. 2014. Water footprint of beef cattle and sheep produced in New Zealand: Water scarcity and eutrophication impacts. Journal of Cleaner Production, 73: 253–262.

zu Ermgassen, E. K., Phalan, B., Green, R. E., & Balmford, A. 2016. Reducing the land use of EU pork production: Where there's will, there's a way. Food Policy, 58: 35–48.

Appendix:

What Greenpeace means by 'ecological livestock'

First and foremost, 'ecological livestock' means much less meat than is currently consumed globally. Any criteria should always work to enhance this key principle: better meat means large reductions in both production and consumption.

A set of ecological and socially just criteria define 'ecological livestock' as the following:

1 Produced with feed not required for human food, and respecting biodiversity and climate:

While human food security is difficult to set limits on, it would include most animals raised on grassland and very little use of feed. A minimum set of general principles include:

- **No feed produced in land linked to deforestation or destruction of intact ecological systems.**
- **Produce feed locally, and as far as possible from waste** (crop residues, food waste, industry waste if safe).
- **Produce feed ecologically, according to the seven Principles of Ecological Farming:**[1] (Supporting food sovereignty, benefiting farmers and rural communities, smarter food production and yields, placing diversity at the center of farming, maintaining sustainable soil health and cleaner water, using ecological pest management, and fostering resilient food systems).
- **What this means specifically per animal sector:**
  - Cows on grasslands and pastures, and feed grown locally.
  - Pigs fed with waste and minimal feed, mostly grown locally.
  - Chicken fed with waste and minimal feed, mostly grown locally.
  - Sheep and goats fed on grasslands and pastures, and feed grown locally (combined with crop residues and waste where appropriate).

1. **Ecological farming:** This method of agriculture ensures healthy farming and healthy food for today and tomorrow, by protecting soil, water and climate. It promotes biodiversity, and does not contaminate the environment with chemical inputs or genetically engineered plant varieties. Ecological farming encompasses a wide range of crop and livestock management systems that seek to increase yields and incomes and maximise the sustainable use of local natural resources whilst minimising the need for external inputs (see Tirado, R. 2015. Ecological farming: the seven principles of a food system that has people at its heart. Greenpeace Research Laboratories Technical Report).

2 Ensuring soil fertility based on manures, compost and the closing of nutrient cycles:

- **Use of soil amendments from crop residues, food waste and manure produced regionally.**[2]
- **Use of legume rotations, compost and organic fertilisers as the principle source of soil fertility.**
- **Substitute chemical fertilisers with organic fertilisers in feed production** (regionally produced).

3 High biodiversity livestock applying to pastures, grasslands, breeds, and feeds:

- **Ensure the preservation of local breeds best adapted to local conditions.**
- **Start to work for the integration of meat, dairy and egg production chains into mixed crop and livestock systems** (e.g. agroforestry).
- **Implement biodiversity measures on production sites** (with list of biodiversity practices).
- **Avoid monoculture production of feed ingredients.**

4 Minimize GHG emissions:

- **Where relevant** (cows, sheep, goats, and in some cases pigs): **implement grassland conservation and practices that increase carbon in the soils (**including limits in the number of animals per hectare, use of cover crops, etc).
- **Feed non-ruminant animals mostly with food waste.**
- **Increase soil carbon by implementing ecological farming practices** (e.g. mulching with crop residues, rotations with legumes, etc).
- **Optimise manure management practices that reduce emissions.**

5 No use of synthetic pesticides or GMOs:

- **Chemical pesticide free.**
- **GMOs free.**

2. The use, recycling or disposal of waste products should always ensure environmental and health safety.

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Ecologically fed cows at Sovanry Nhem's ecological farm in Takeo province, Cambodia

6 Limit the use of antimicrobials to the medical treatment of animals:

- **Reduce use of all classes of medically important antimicrobials in food-producing animals.**
- **Completely restrict use of all classes of medically important antimicrobials in food-producing animals for growth promotion.**
- **Completely restrict use of all classes of medically important antimicrobials in food-producing animals for prevention of infectious diseases that have not yet been clinically diagnosed.**
- **Any new class of antimicrobials or combination developed for human use will be considered critically important unless categorized otherwise by the World Health Organisation (WHO).**
- **Restrict the incorporation of new and upcoming medically important antimicrobials that are not currently used in food production.**
- **Establish surveillance monitoring of antimicrobial agents and antimicrobial resistance in the environment.**
- **Eliminate discharges, losses and emissions of antimicrobial agents to the environment.**

7 Ensure the highest animal welfare standards:

- **No factory farms** (enclosed facilities and individual confinement for animals).
- **No non-curative, non-essential interventions.**
- **Provide a suitable environment.**
- **Prevention of animal cruelty through the whole supply chain.**
- **Proper measurement and documentation of standards.**

8 Ensure human rights along the value chain (farmers, labourers, rural communities, impacted communities):

- **Ensure the rights of Indigenous Peoples are fully respected, including their right to consultation and to give or withhold their free, prior and informed consent.**
- **Production shall not negatively impact, directly or indirectly, indigenous' rights and resources.**
- **Ensure the rights of contract farmers in adherence with the UN Right to Food.**
- **Ensure fair rural livelihoods and just economic transitions for livestock producers.**

Glossary

Antimicrobial resistance
Antimicrobial resistance occurs when microorganisms such as bacteria, viruses, fungi and parasites change in ways that render the medications used to cure the infections they cause ineffective. When the microorganisms become resistant to most antimicrobials they are often referred to as 'superbugs'. This is a major concern because a resistant infection may kill, can spread to others, and imposes huge costs to individuals and society.[1]

Blue water
This is the water that contributes to surface and groundwater reservoirs.

Biodiversity
This includes all the living things (plants, animals, fungi and microbes) on Earth or in a certain habitat. Biodiversity is often referred to in terms of plant and animal communities that form part of balanced ecosystems. Imbalanced ecosystems can often result in one species becoming more or less abundant, with changes to communities that are often long-term or irreversible.

Business as Usual
The baseline scenario is the Business as Usual (BAU) scenario, which assumes no major changes in trajectory, so that normal circumstances can be expected to continue unchanged.

Carbon cycle
The series of processes by which carbon compounds are interconverted in the environment.

Cardiovascular disease
Stroke, coronary heart disease, aortic disease and peripheral arterial disease are all symptoms of cardiovascular disease.

1. http://www.who.int/features/qa/75/en/

Concentrated animal feeding operations (CAFOs)
These are farms where over 1000 'animal units' are confined for over 45 days per year. The United States Department of Agriculture defines an animal unit as 'an animal equivalent of 1000 pounds (~ 450 kg) live weight, which equates to around 1000 head of beef cattle, 700 dairy cows, 2500 pigs weighing more than 250 kg, 125,000 broiler chickens and 82,000 laying hens.

Diabetes
Diabetes is a serious lifelong condition that occurs when the amount of glucose (sugar) in the blood is too high. If left untreated, high blood glucose levels can cause serious health complications. There are two main types of diabetes: Type I and Type II.

Deforestation emissions
Deforestation results in carbon that has been stored in the plant material (leaves, wood, roots) and soil (microbes) to be released into the atmosphere.

Ecological farming
This method of agriculture ensures healthy farming and healthy food for today and tomorrow, by protecting soil, water and climate. It promotes biodiversity, and does not contaminate the environment with chemical inputs or genetically engineered plant varieties. Ecological farming encompasses a wide range of crop and livestock management systems that seek to increase yields and incomes and maximise the sustainable use of local natural resources whilst minimising the need for external inputs (see Tirado, 2015. Ecological farming: the seven principles of a food system that has people at its heart. Greenpeace International).

Ecological livestock
This method of livestock production integrates farm animals as essential elements in the agriculture system; they help optimise the use and cycling of nutrients and, in many regions, provide necessary farm working force. Ecological livestock relies on grasslands, pasture and residues for feed, minimising use of arable land and competition with land for direct human food production, and protecting natural ecosystems within a globally equitable food system (see Tirado & Kruszewska 2012. Ecological Livestock: Options for reducing livestock production and consumption to fit within ecological limits, with a focus on Europe Greenpeace Research Laboratories technical report).

Eutrophication
This is the over-enrichment of nutrients in aquatic (freshwater and marine) systems that can cause algal blooms and low oxygen levels.

Gene-editing
The use of biotechnological techniques to make changes to specific DNA sequences in the genome of a living organism.

Global land-use change
Globally, land is used for a number of human activities and change in land-use, such as when natural habitats are altered, is a major driver of environmental change at local, regional, and global scales, with important impacts on biogeochemical cycling, ecosystem structure and function, and greenhouse gas emissions.

Green water
This is gathered from rainwater.

Greenhouse gases and carbon dioxide equivalent (CO_2e)
In simple terms, carbon dioxide (CO_2) cycles as part of natural, global carbon cycle processes, and by burning fossil fuels; methane (NH_4) is emitted from agricultural practices and burning fossil fuels; nitrous oxide (N_2O) is emitted from industrial and agricultural practices and burning fossil fuels; fluorinated gases, such as hydrofluorocarbons. Different gases have different Global Warming Potentials (GWP) and therefore a method to compare them using one unit, carbon dioxide equivalent (CO_2e) is used as a reference value. The GWP of a particular gas is measured against CO_2 over a standard period of time of 100 years. Compared to CO_2, methane is 25 times more potent and N_2O is 298 times more potent.

Grey water
This is the volume of water that is required to dilute, or assimilate, a pollutant.

Holistic
A systemic approach in which the parts of something are considered to be intimately interconnected and explicable only by reference to the whole. Ecological problems usually require holistic solutions.

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Industrial agriculture
This is a way of growing food that includes the intensive use of external inputs, such as fertilisers, pesticides and antibiotics. Industrial agriculture is generally focused on maximising yields, often at intensive scales.

Livestock
Livestock are domesticated animals raised in an agricultural setting to produce commodities such as meat, eggs, milk, fur, leather, and wool, and often also to carry out work.

Nitrogen cycle
The continuous processes that result in atmospheric nitrogen and nitrogenous compounds in the soil being converted, by nitrification and nitrogen fixation, into substances that can be used by green plants. The substances are then returned to the air and soil as a result of the decay of plants and denitrification.

Paris Climate Agreement
The Paris Agreement was adopted in Paris on December 12 2015, as part of an international treaty – the United Nations Framework Convention on Climate Change – to increase global efforts to limit "a global temperature rise this century to well below 2 °C". There are 197 Parties to the Convention of which to date 174 have ratified. The Paris Agreement came into force on November 4 2016.

Phosphorus cycle
This is the biogeochemical cycle that describes the movement of phosphorus through rocks and soils, water and living things on Earth. Unlike many other biogeochemical cycles, the atmosphere does not play a significant role in the movement of phosphorus.

Planetary boundaries
These boundaries describe the systems that are vital for human existence on Earth and aim to quantify the current position in 'operating space' within them – from healthy to beyond the safe limits. Nine planetary boundaries have been described so far: 1) land system change, 2) biosphere integrity or biodiversity loss, 3) biogeochemical flow (nitrogen and phosphorus pollution), 4) climate change, 5) freshwater use, 6) novel entities, 7) ocean acidification, 8) stratospheric ozone depletion and 9) atmospheric aerosol loading.

Plant-based/plant-rich diet
This is a diet that is based primarily on vegetables, pulses, fruits and nuts. It might also include small amounts of animal products, such as dairy, eggs and meat products very sparingly. Greenpeace recommendation is for no more than 300 g of meat products per week, and 600 g of milk per week (to be achieved globally by 2050). These foods can be grown using the ecological agriculture principles promoted by Greenpeace. The plant-based diet is also referred to as plant-rich diet.

Vegetarian diet
Usually referred to as the lacto-ovo vegetarian diet, which is a plant-based diet with a moderate intake of eggs and dairy products. It is the most common form of plant-based diet and fulfils all nutritional requirements. The lacto-ovo vegetarian diet, as the plant-based diet, is safe and healthy for pregnant and breastfeeding women, babies, children, teenagers and seniors.

Vegan diet
This is a diet based only on plant foods and with no animal products consumed. This diet is appropriate for people at all stages of life and provides all the necessary nutrients, vitamins, minerals and amino acids apart from vitamin B12 (a B12 supplement might be necessary).

Zoonoses
These are diseases that can be transferred between animals and humans.

Scientific background
on the Greenpeace vision of the
meat and dairy system towards 2050

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