September 27, 2020

Bending the Curve: The Restorative Power of Planet-based Diets

PREFACE

From a global agenda to local actions

The 2020 *Living Planet Report* showed us that drivers linked to the food system are the biggest causes of biodiversity loss on land and in freshwater. It also showed us that, if we combine increased conservation efforts with a transformation of the food system, it is possible to halt our degradation of nature and reverse the damage we have caused. Transforming how we produce and consume food is a necessity for a nature-positive, carbon-neutral future.

Dietary change is a central component of a food system transformation. What's more, a rise in conscious consumption and shifts in market demand can accelerate other key actions such as reducing food loss and waste, and adopting nature-positive production practices. There have been many recent calls for action on diets, but most of these have looked at solutions from a global perspective. Dietary shifts can only be achieved through local action, but there has not been clarity around how countries existing in different contexts can make these shifts. This is particularly a problem for those countries that need to increase food consumption to address hunger (approximately one in twelve people go hungry every day!) and improve human health; they lack a consistent framework in which to understand how to minimize environmental impacts. Meanwhile, richer countries rarely equate human health to environmental health and often encourage eating patterns which are not ambitious enough to restore our planet.

The global imperative must be translated into national and sub-national contexts, by understanding the impacts of shifting consumption patterns, on both human and environmental health. There is no one-size-fits-all solution and we need flexible, adaptable models which can be tailored to different cultures, but consistently deliver high human health benefits and low environmental impacts: *Planet-based diets.* The need to provide countries with localized information which allows them to build their own solution, within a flexible model guided by a set of key principles, led us to develop this report and its accompanying assets.

Bending the curve: The restorative power of planet-based diets is a scientific report in which we explore three things: firstly, the current impacts of food consumption, at a country level, on both human and environmental health; secondly, the extent of change in impacts on human and environmental health if current consumption shifted to different diets; thirdly, the strategic areas in which dietary shifts can have most significant impact on bending the curve on the negative impacts of the food system – moving from a system which exploits the planet to one which restores it for nature and people.

The evidence in this report shows there is an opportunity to improve human and environmental health by making dietary shifts that eliminate over-consumption of any foods, and that doing so can help us achieve the Sustainable Development Goals and the Paris climate goals. There is a clear role for national governments to play, and reforming National Dietary Guidelines is one tool at their disposal. Of course, there may be trade-offs involved – a planet-based diet will support sustainable production systems and reduce food waste, but improving some environmental aspects at a national level may mean some others suffer. There can also be impacts outside the food system and on socio-economic factors which will require government action, broad coalitions and social

safety nets to alleviate such impacts. That's why dietary transitions must be part of a holistic food system transformation designed by multiple stakeholders, and be accompanied by nature-positive production practices and reductions in food loss and waste.

WWF is committed to both reducing the footprint of our consumption and eliminating habitat conversion, thus working to help transform the food system – from production to consumption to loss and waste. We are delighted to present this report, identifying specific areas in which individual countries can adopt planet-based diets. We look forward to working with civil society organisations in partnership with both the public and private sector to achieve dietary shifts which align human and environmental health for the benefit of people and nature and identify the areas in which other actions are also required.

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EXECUTIVE SUMMARY

Numerous recent studies have shown that a global shift toward healthier, more sustainable diets will combat climate change, improve human health and food security, reduce biodiversity loss, save lives, decrease the risks of future pandemics, and unlock economic benefits. This research has helped establish the global impacts of the current food system; now these global recommendations must be translated into local reality. We begin this work by offering a detailed analysis of the impacts of various dietary patterns (including national dietary guidelines) on several health and environmental variables in 147 countries around the world, highlighting impacts using a handful of examples.

We frame the analysis around five strategic actions that can be strongly influenced by dietary shifts and are needed to bend the curve on the negative impacts of the food system, moving from one that exploits the planet to one that restores it for nature and people. These actions are 1) reversing biodiversity loss; 2) living within the global carbon budget for food; 3) feeding humanity on existing cropland; 4) achieving negative emissions; and 5) optimizing crop yields. National-level success on these strategic actions through dietary changes is critical to building a nature-positive food system that helps to reverse the loss of nature to restore both people and planet.

Dietary shifts toward planet-based diets can contribute to climate, biodiversity and sustainable development goals. As the *Living Planet Report 2020* highlights, achieving these international goals and commitments is more urgent than ever: "humanity's increasing destruction of nature is having catastrophic impacts not only on wildlife populations but also on human health and all aspects of our lives."

Currently, we are producing enough food to feed the planet, but global food production does not respect planetary boundaries. We are now beginning see the consequences of our actions and the warning signs of a planet in crisis. Dietary shifts are key in reversing course so that food is produced in a way that restores the planet, not destroys it. In the end, dietary changes will play out at local levels and differently in countries around the world. Understanding the impacts of country-level dietary shifts and how the strategic actions outlined in this report synergistically interact is a critical first step toward taking action.

BOX: What are planet-based diets?

Planet-based diets are "win-win" consumption patterns that are high on human health benefits and low on environmental impacts. They comprise healthy and sustainable ingredients produced within planetary boundaries and adaptable to local contexts. These diets discourage over-consumption of any food, to the extent that over-consumption negatively impacts biodiversity, the environment and human health. In particular, a large body of evidence has shown that reducing over-consumption of animal-source foods, by increasing the relative consumption of plant-based foods, confers both environmental and health benefits (win-win).

KEY POINTS

1) Eating a planet-based diet can unleash a multitude of environmental benefits including combating the climate and biodiversity crises, reducing pressure on land, and relieving water stress and eutrophication of lakes and oceans. But these impacts play out differently in countries around the world and must to be assessed separately for each country.

2) Eating a planet-based diet improves health outcomes in all countries, including reductions in premature mortality by up to 30%. Some countries would see their largest health gains from reductions in overall daily food intake and increased consumption of plant foods while other countries would see the largest health gains from increased consumption of total daily food intake and adopting a more balanced diet.

3) A shift toward planet-based diets is a powerful lever for achieving more ambitious nationally determined contributions (NDCs) to the Paris Agreement, a more holistic post-2020 global biodiversity framework, and a renewed commitment to the Sustainable Development Goals (SDGs).

4) National dietary guidelines (NDGs) are important tools for changing diets and act as a bridge between global dietary recommendations and local context and relevance. Current NDGs, however, are not ambitious enough to achieve global goals and commitments and should therefore be reviewed and updated to ensure they are in line with global health and environmental targets.

5) A full range of policy levers need to be implemented to leverage dietary changes as a tool for achieving the five strategic actions outlined in this report. Countries must commit to closing the evidence gaps that remain regarding specific implications of dietary shifts at the national level and which actions are most effective for their context.

FIVE STRATEGIC ACTIONS

Five strategic actions, which can be strongly influenced by dietary changes, need to be achieved to bend the curve on the negative impacts of the food system (Figure 1), moving from one which exploits the planet to one that restores it for nature and people. These are:

1) **Reversing biodiversity loss** – rapidly slow down and move toward zero loss of biodiversity from food production while also using agricultural systems to restore biodiversity across the planet.

2) **Living within the global carbon budget for food** – reduce total greenhouse gas emissions from food production to at most 5 Gt CO_2-eq, the maximum allowable total global emissions (or carbon budget) from producing our food.

3) **Feeding humanity on existing cropland** – stop expansion of new cropland, or any agricultural land, at the expense of natural habitats, supplying future food demand on the same area of land as today (or ideally less).

4) **Achieving negative emissions** – move agriculture from a carbon source to a carbon sink, including by freeing up existing agricultural lands that can be reforested or restored and rapidly implementing food production practices that increase carbon storage on existing cropland.

5) **Optimizing crop yields** – use all agricultural lands to their maximum potential including optimizing crop yields through better food production practices that more efficiently use water and fertilizers, preserve ecosystem functions and contribute to resilient landscapes.

Figure 1. National level success on five strategic actions is needed to bend the curve on the negative impacts of the food system, moving from one that exploits the planet to one that restores it for nature and people.

WHAT WE EAT MATTERS

Numerous recent studies have pointed to the sweeping benefits of shifting diets. This research has shown that a global shift toward healthier, more sustainable diets will combat climate change and food insecurity,[1] reduce biodiversity loss,[2] improve human health,[3,4] significantly reduce premature mortality,[5] make national supply chains more resilient to shocks,[6] reduce the financial risks associated with meat production,[7] help decrease the risks of future pandemics,[8,9] and unleash US$4.5 trillion in new business opportunities while saving US$5.7 trillion a year in damage.[10]

It is now clear that what we eat matters and matters a lot. Research to date has helped to establish the global impacts of our dietary choices but has so far said very little about how shifts toward more planet-friendly diets could impact individual countries. In this report we begin the work of translating global recommendations about the need for a shift toward more healthy and sustainable diets into the potential impacts of such a shift on individual countries. We do this to assist countries in their efforts to use diets as a springboard to achieving international commitments, including strengthening nationally determined contributions (NDCs) to the Paris Agreement, establishing a holistic post-2020 global biodiversity framework, and renewing commitment to the Sustainable Development Goals (SDGs) in preparation for (and beyond!) the UN Food Systems Summit in 2021.

To accomplish this, we offer a detailed analysis of food consumption patterns in 147 countries and 6 regions and the national dietary guidelines (NDGs) of 75 countries. For each country and region, we assess the impacts of diets – current as well as NDGs and several other dietary patterns – on various environmental and health indicators (see Table 1). We frame the analysis around five strategic actions that are strongly influenced by diets and are needed to bend the curve on the negative impacts of the food system, moving from one which exploits the planet to one that restores it for nature and people. All country level estimates represent the impacts of food consumption not production, and therefore include imported food, but exclude the impacts of food produced domestically and then exported.

Table 1 – Dietary patterns and environmental and health indicators assessed. To inform the analysis, we used UN Food and Agriculture Organization (FAO) food balance sheets to determine current food consumption in the countries and regions assessed. To evaluate the NDGs across all countries a graded coding method was used to extract quantitative values from each guideline.[11] For analysing the environmental impacts, a life-cycle assessment (LCA) approach was used because it allows multiple environmental impact indicators to be estimated across the full supply chain.[12]

Dietary patterns assessed	Environmental and health indicators assessed
Current diet – the average diet currently consumed by the citizens of a country.	**GHG emissions** – the greenhouse gas emissions related to food systems including all emissions along the food supply chain, from deforestation and land conversion, input production, fertilizer application, energy use on farm, animal production, aquaculture, processing, packaging, transport and retail.
National dietary guidelines – Dietary guidelines put forward by the relevant government department of each country.	**Carbon sequestration** – the climate benefit of vegetation regrowth following reductions in agricultural land (only including reversion to native ecosystems – pre-agriculture).

Flexitarian – plant-based but allowing for moderate animal-source food consumption, including meat.[5]	**Eutrophication** – the freshwater and marine eutrophication potential from nitrogen and phosphorus pollution related to food systems.
Pescatarian – replacing meat with two-thirds fish and seafood and one-third fruit and vegetables.	**Water use** – the freshwater withdrawals related to food production. Includes irrigation water, animal drinking water, and water used during food processing.
Vegetarian – replacing meat with two-thirds legumes and one-third fruit and vegetables.	**Cropland use** – the cropland used for food production ("cropland demand"), both domestically and abroad. Including land use for animal feed.
Vegan – replacing all animal-source foods with two-thirds legumes and one-third fruit and vegetables.	**Grazing land use** – rangelands and pastures related to food consumption, both domestically and abroad.
	Biodiversity loss – the number of species expected to go extinct as a result of food production for various diets.
	Premature mortality – the change in premature mortality from diet-related non-communicable diseases.

We know that transforming the food system is bigger than what can be accomplished by dietary shifts alone.[5] This includes necessary reductions in food loss and waste and changes in food production practices. We focus on diets, however, because dietary shifts are a lever that can be moved quite rapidly and many governments already have NDGs that can be used as a starting point to accelerate healthy eating patterns.[13] In addition, eating foods that have a smaller negative impact on human health and the environment (i.e. planet-based diets) is a "win-win" opportunity for countries to achieve both health and environmental goals at the same time.[14] Given this, we believe that dietary shifts are a key leverage point for helping to address the multiple converging environmental and health crises that we are experiencing today.

It may seem that shifting diets is a nearly impossible task, but major dietary changes are a surprisingly common occurrence. Over the last half-century, many countries have undergone a nutrition transition from diets low in fat, sugar and meat to a diet dominated by animal-source foods, refined grains, saturated fats and sugar[15,16] and fad diets such as the keto, paleo and Zone diets are always quick to penetrate popular culture. The power to shift diets is also more often in the hands of the individual than for other environmental choices.

NATIONAL DIETARY GUIDELINES

We assessed NDGs for 75 countries as they are important tools for changing food systems.[13] NDGs are public, government-endorsed documents that are intended to provide generalizable recommendations and advice on healthy diets and lifestyles and act as a bridge between global dietary recommendations (e.g. World Health Organization (WHO), EAT-*Lancet* Commission) and local context and relevance. They are a key component of public health policy and an essential first step to promoting healthy eating habits in a country, often through educational programmes or public awareness campaigns. In line with the key role they can play and given the unique nature of diets across the world, we believe NDGs can act as a valuable tool to raise awareness, influence policy, guide the private sector and inform consumer choice.

ENVIRONMENTAL AND HEALTH IMPACTS OF FOOD

Currently, our dietary choices are driving a system of food production that is destroying the planet (Figure 2).[1,2,5] The agricultural revolutions of the past have allowed us to feed more people, but this has come at the expense of forests, grasslands, wildlife, water and a stable climate. This exploitation of the environment is behind multiple converging global crises including the climate and biodiversity crises, which alone have the ability to disrupt the stability of the planet. Luckily, we are waking up to the fact that what we eat really does matter and that our everyday food choices are among the most important individual actions we can take for the environment and our health.

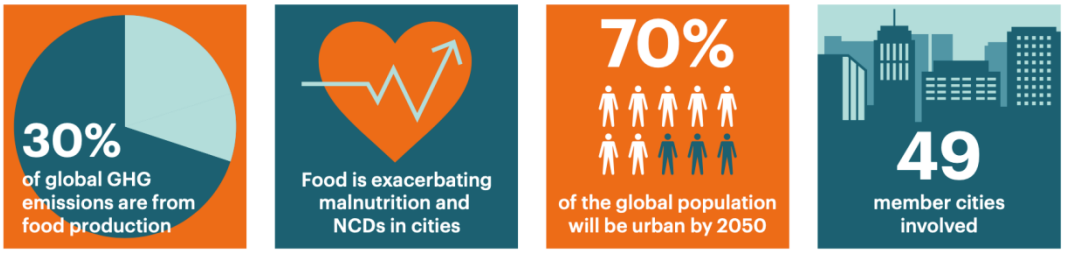

Figure 2. The global food system is a leading contributor to our rapidly deteriorating environment and the unravelling of nature.

PLACEHOLDER GRAPHIC ABOVE FOR DESIGN INSPIRATION - Graphic on environmental impacts of food systems. Responsible for 24% of GHG emissions, 70% of freshwater withdrawals, main driver of biodiversity loss and tropical deforestation, and increasing risk for future pandemics.

Our dietary choices are also damaging our health (Figure 3). These choices are characterized by either excess or insufficiency. People in some countries have an abundance of food and choice while people in other countries still lack both. This highly polarized reality has led to a situation where many countries face a growing obesity epidemic, in others hunger and undernutrition persist, and in far too many both realties exist at the same time.[3] Unhealthy diets now pose a greater risk of morbidity and mortality than unsafe sex and alcohol, drug and tobacco use combined.[16]

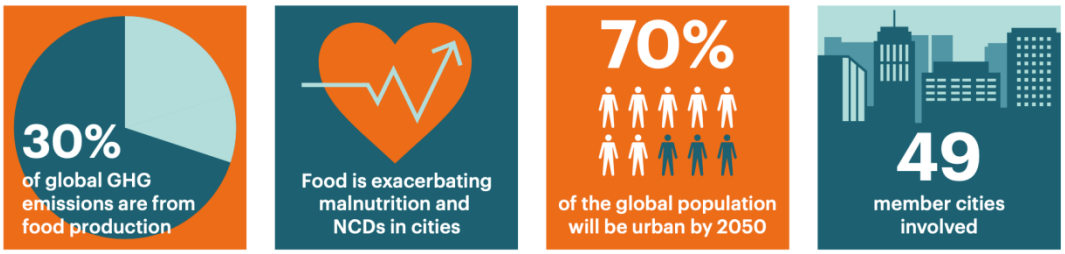

Figure 3. The global food system is a major contributor to much of the ill-health that we see around the world.

PLACEHOLDER GRAPHIC ABOVE FOR DESIGN INSPIRATION - Graphic on health impacts of food systems. One in three overweight or obese, one in nine hungry or undernourished, leading cause of death, and no country on course to meet 2025 global nutrition targets.

PLANETARY BOUNDARIES FOR FOOD

The planetary boundaries framework identifies nine systems and processes that are important for regulating the state of the Earth system (Figure 4a). The framework identifies boundaries for each system or process that when crossed could trigger rapid, non-linear and potentially irreversible changes to the stability of the Earth system. Within the boundaries is the "safe operating space" for humanity – this is within the inner red circle and shown in green in Figure 3a below, while yellow represents the zone of uncertainty (increasing risk) and red the high-risk zone.[17]

For the food system, the EAT-*Lancet* Commission used the planetary boundaries as a framework and proposed six boundaries that global food production should stay within to decrease the risk of irreversible and potentially catastrophic shifts in the Earth system.[5] These planetary boundaries for food production conceptually define the upper limit of environmental impacts for food production at the global scale (Figure 4b).

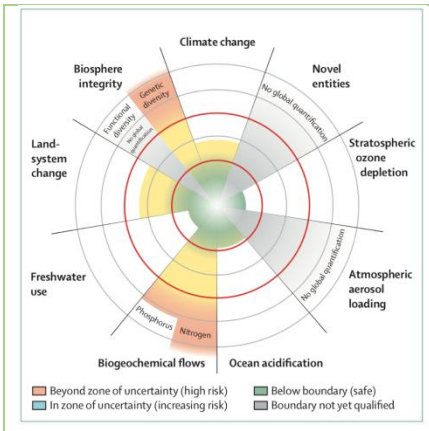

Figure 4a. The planetary boundaries framework describing the upper limits of environmental impact from all human activities at the global scale.

Source: Whitmee et al. 2015 [18]

Earth system process	Control variable	Boundary (Uncertainty range)
Climate change	GHG emissions	5 Gt CO_2-eq yr^{-1} (4.7 – 5.4 Gt CO2-eq yr^{-1})
Land-system change	Cropland use	13 M km^2 (11–15 M km^2)
Freshwater use	Water use	2,500 km^3 yr^{-1} (1000–4000 km^3 yr^{-1})
Nitrogen cycling	N application	90 Tg N yr^{-1} (65–90 Tg N yr^{-1}) * (90–130 Tg N yr^{-1})**
Phosphorus cycling	P application	8 Tg P yr^{-1} (6–12 Tg P yr^{-1}) * (8–16 Tg P yr^{-1})**
Biodiversity loss	Extinction rate	10 E/MSY (1–80 E/MSY)

*Lower boundary range if improved production practices and redistribution are not adopted.
**Upper boundary range if improved production practices and redistribution are adopted and 50% of applied phosphorus is recycled.

Figure 4b. The planetary boundaries specific to food production that define the upper limits of the environmental impact that food production can have at the global scale.

Source: Adapted from Willett et al. 2019 [5]

Currently, we are producing enough food to feed everyone on the planet, but in the process we are not respecting planetary boundaries. If we did respect all boundaries, however, without any changes in how we currently produce, consume and waste food, then we would only be able to produce food for 3.4 billion people.[19] This clearly shows that current methods of food production and dietary patterns are unsustainable. This message was highlighted in the 2020 *Living Planet Report*, which stated, "The main cause of the dramatic decline in species populations on land … is habitat loss and degradation, including deforestation, driven by how we as humanity produce food." [20]

There is good news, however: when implementing dietary changes, reducing food loss and waste, and applying ambitious changes in food production practices, up to 10 billion people could be fed within planetary boundaries[5,19,21]

In this report we focus on the dietary change part of the challenge and explore the impact of various dietary changes in countries around the world. The impacts of changes in food production practices and reductions in food loss and waste are explored in more depth in other studies.[5,21]

FOOD CONSUMPTION PATTERNS AROUND THE WORLD

An entry point for making sense of the health and environmental impacts of diets is an understanding of consumption patterns around the world. Currently, consumption varies widely and can best be characterized by massive inequality. Although undernutrition and overweight and obesity affect most all countries, the rate of underweight people is up to 10 times higher in the poorest countries while the rate of overweight and obese people is up to 5 times higher in the richest countries.[3] These health outcomes mirror current consumption patterns in the richest and poorest countries, with European countries consuming approximately 600 g/day more food (1,800g/day – Figure 5) than African countries (1,200/day – Figure 6).

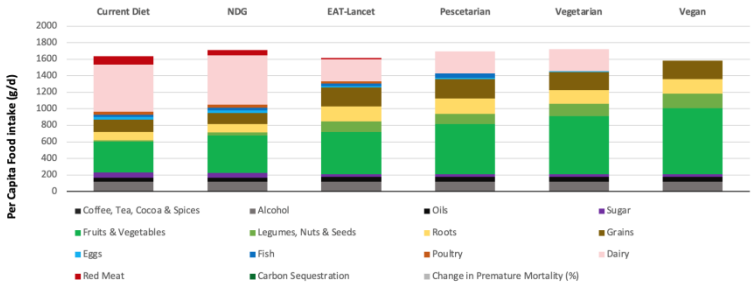

Figure 5. Current per capita food consumption patterns in European countries and the food intake (g/day) required to shift toward NDGs and other dietary patterns.

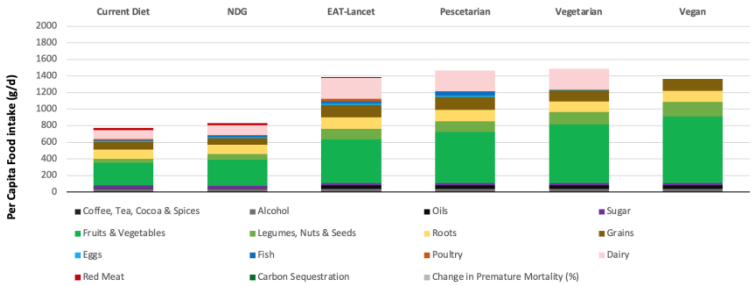

Figure 6. Current per capita food consumption patterns in Africa and the food intake (g/day) required to shift toward NDGs and other dietary patterns.

Analyses at regional scales, however, often hide inequalities that exist between countries, even among those with the largest economies.[14] For example, daily food consumption in the United States (nearly 2000g/day; Figure 7) is almost double that of Indonesia (approximately 1000g/day; Figure 8). This includes much higher consumption of foods such as red meat (116g/day) and dairy (594 g/day) in the United States compared to Indonesia (13.8 g/day red

meat and 34.7g/day dairy). Shifting toward more healthy and sustainable diets in these countries would require a large reduction in consumption of these foods in the United States. However, overconsumption of other foods that can cause poor health, such as highly processed white rice, would need to decrease in Indonesia.

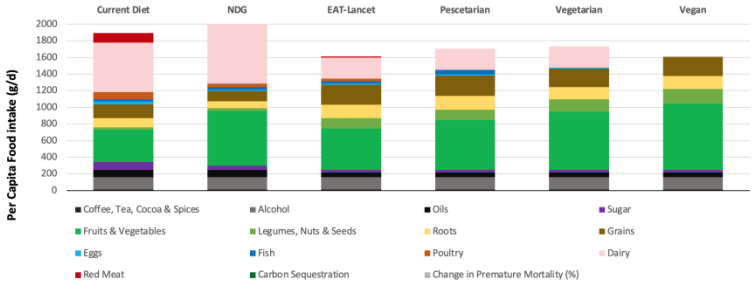

Figure 7. Current per capita food consumption patterns in the United States and the food intake (g/day) required to shift toward NDGs and other dietary patterns.

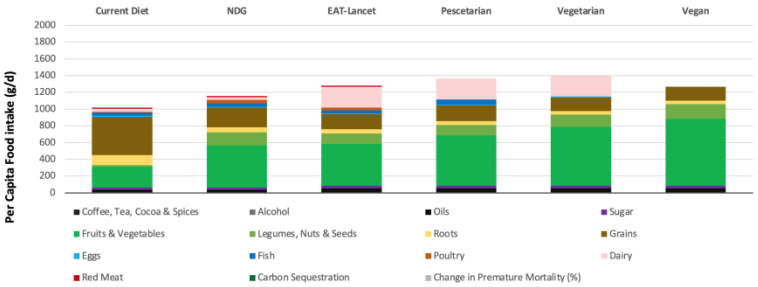

Figure 8. Current per capita food consumption patterns in Indonesia and the food intake (g/day) required to shift toward NDGs and other dietary patterns.

Important to note is the fact that in most countries, NDGs are closer to current consumption levels than other planet-based dietary patterns and in some cases appear to support a status quo that is either insufficient or not supported by the latest science on healthy diets. In a recent study, researchers found that most NDGs are incompatible with global health and environmental targets such as the Paris Agreement or the global health agenda on non-communicable diseases.[11]

Despite this, some countries are taking significant steps to promote healthy dietary patterns through their NDGs. Canada recently launched a food guide that recommends having plenty of vegetables and fruits (half of the plate), protein foods (quarter of the plate), wholegrain foods (quarter of the plate) and making water the drink of choice. The "*guide emphasizes getting protein from plant-based sources such as beans, lentils and nuts, rather than always choosing animal-based foods such as milk, meat and poultry*." [22]

This is one of several examples of countries raising the ambition of their NDGs and offers encouraging signs that NDGs are becoming more closely aligned with the latest science on foods that optimize human health.[5] However, significant steps still need to be taken to raise the level of ambition of NDGs in all countries to ensure they are in line with achieving both global health and environmental targets.

HEALTH IMPACTS OF DIETS

Several recent studies have demonstrated the significant impact that increasing consumption of plant-based foods relative to animal-source foods can have on human health. The EAT-*Lancet* Commission on Food, Planet, Health found that premature mortality could be reduced for up to 11 million people by a shift toward a healthy flexitarian diet.[5] Another study found that adopting NDGs could reduce premature mortality by, on average, 15% globally, while adopting the EAT-*Lancet* diet was associated with 40% greater reductions (21% overall) in premature mortality.[11] A Global Burden of Disease (GBD) study found that 11 million deaths and 255 million disability-adjusted life-years (i.e. the number of years lost to ill-health, disability or early death) were mainly attributable to dietary risk factors that include high intake of sodium, low intake of wholegrains and low intake of fruits in many countries.[23]

Our results also show positive health gains in all countries by increased consumption of plant-based foods relative to animal-source foods in diets. Germany, for example, would see up to nearly a 20% reduction in premature mortality (Figure 9). This is mainly attributed to decreasing daily food intake (g/day) by around 10% and increasing the relative proportion of fruits, vegetables and legumes in a diet compared to red meat and dairy. This result is supported by the GBD and EAT-*Lancet* studies.

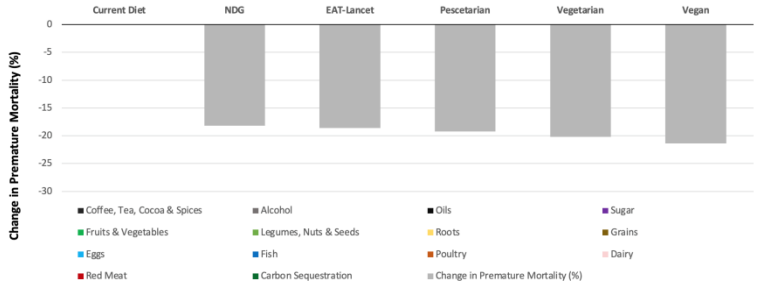

Figure 9. Percentage reduction in premature mortality in Germany from a shift toward NDGs and other dietary patterns.

Argentina would see up to nearly a 30% reduction in premature mortality with a shift toward greater consumption of plants relative to animals (Figure 10). As in Germany, this is mainly attributed to a decrease of total daily food intake (g/day) and replacing red meat and dairy with fruits, vegetables and legumes.

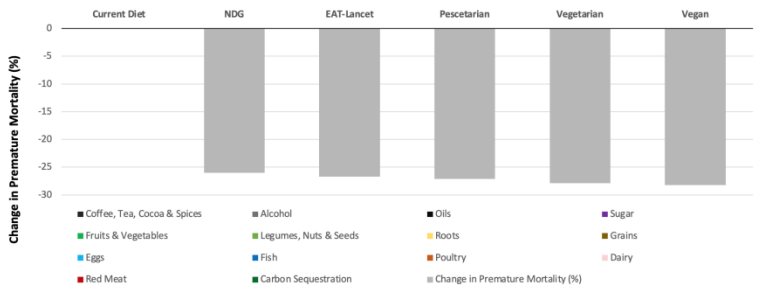

Figure 10. Percentage reduction in premature mortality in Argentina from a shift toward NDGs and other dietary patterns.

Kenya would see smaller but still significant reductions in premature mortality, from 5%, if NDGs were followed, up to a maximum reduction of approximately 9% for a shift toward a vegan diet (Figure 11). These reductions come mainly from a large increase (up to nearly 20%) in daily food intake (g/day) and an increase in daily consumption of fruits, vegetables, nuts and legumes.

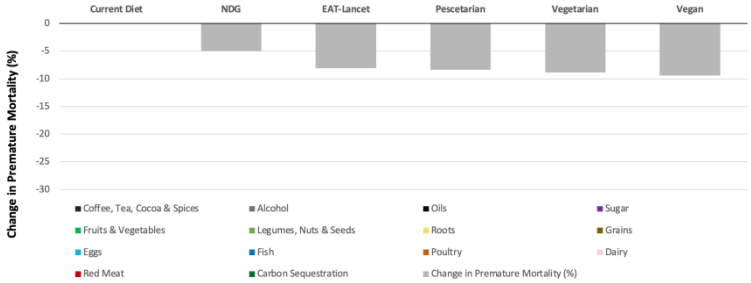

Figure 11. Percentage reduction in premature mortality in Kenya from a shift toward NDGs and other dietary patterns.

Takeaway: Eating a planet-based diet improves health outcomes in all countries, including reductions in premature mortality. Some countries would see their largest health gains from reductions in overall daily food intake and increased consumption of plant foods. Other countries would see the largest health gains from increased total daily food intake and adopting a more balanced diet. These results again highlight the significant inequalities that exist in our current food system. What these country-level results fail to show, however, are the inequalities that exist within countries and communities, with vulnerable groups being the most affected.[3]

A FOOD SYSTEM THAT RESTORES NATURE

Below we discuss five strategic actions that together can help to bend the curve on the negative impacts of the food system, moving from one which exploits nature to one that restores it. For each action we explore the environmental impact that various dietary pattens can have when adopted universally by a country. Each of these actions interplay with each other in important ways and national-level success on all of them is critical to building a nature-positive food system that helps to reverse the loss of nature to restore both people and planet.

Strategic action 1: Reversing biodiversity loss

What needs to happen – rapidly slow down and move toward zero loss of biodiversity from food production while also using agricultural systems to restore biodiversity across the planet.

Biodiversity generates critical ecosystem services that support food production including pollination, creating and maintaining healthy soils, pest control, water regulation, carbon storage, and habitat for wildlife.[24] All of these make food systems more resilient to shocks and stresses, including those caused by a rapidly changing climate.

In addition, agricultural biodiversity (i.e. crop and livestock diversity) is essential to resilient food systems, yet only a handful of species are used today. Of the 6,000 plant species that have been cultivated for food production, fewer than 200 are consumed today and just 9 account for

nearly 70% of all food produced.[24] Many underused plant species are very healthy and have traits of interest for adapting food production to climate change. These qualities are especially important considering the increasing risk that climate change poses to crop yields and the nutritional content of foods.

Despite the central role of biodiversity in food production, we are losing species at a rate 100–1,000 times greater than the underlying rate during the Holocene and have entered the sixth mass extinction. Terrestrial and aquatic habitat loss, habitat fragmentation, climate change, chemical pollution, invasive species and unsustainable harvest of wild species are primary drivers.[25,26] However, habitat loss and fragmentation, particularly conversion of land for food production, is the single greatest current driver of biodiversity loss.[20,27] Based on the IUCN classification of bird and mammal extinction risks, 80% of the mammal and bird species that are threatened with extinction have agriculture as a cause of those threats (Figure 12).

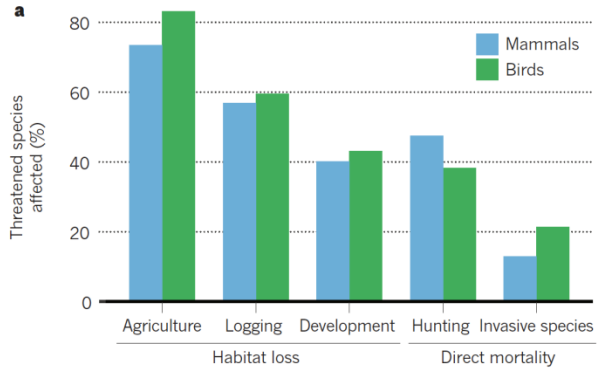

Figure 12. Relative impact of agriculture and other activities on mammal and bird species threatened with extinction based on IUCN extinction risks. Source Tilman et al. (2017).[27]

Increasing consumption of plant-based foods relative to animal-source foods is often cited as a method for reducing biodiversity loss, with the main driver being reduced pressure on natural ecosystems at risk of conversion (see Strategic Actions 3 and 4 for more discussion on dietary shifts and land use).[28-30] At the global and certain regional and national levels this assertion is consistent with our results, in which we estimate the number of species that become destined for extinction each year because of agricultural land use. A shift toward more plant-based foods could reduce global biodiversity loss by between 5% (flexitarian diet) up to 46% (vegan diet – Figure 13). In the Latin America/Caribbean region biodiversity loss could be reduced by 50% to 70% depending on the dietary pattern adopted (Figures 14 and 15).

The numbers presented here most likely underestimate the potential for decreasing biodiversity loss through dietary shifts. This is because these estimates do not include the restorative potential for species as we spare farmland and adopt more biodiversity friendly production practices.

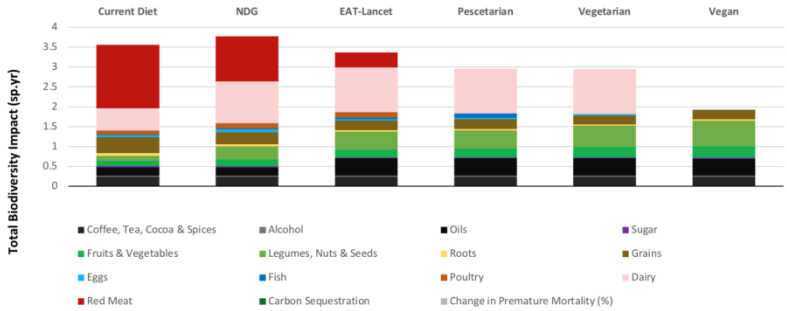

Figure 13. Number of total species expected to go extinct globally as a result of food production for current diets, NDGs, and other dietary patterns.

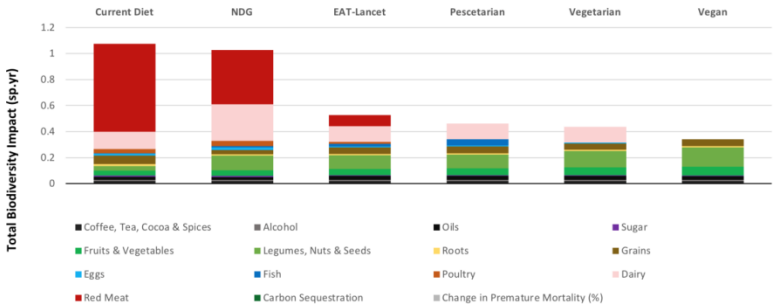

Figure 14. Number of total species expected to go extinct as a result of food production for current diets, NDGs, and other dietary patterns: Latin America and the Caribbean.

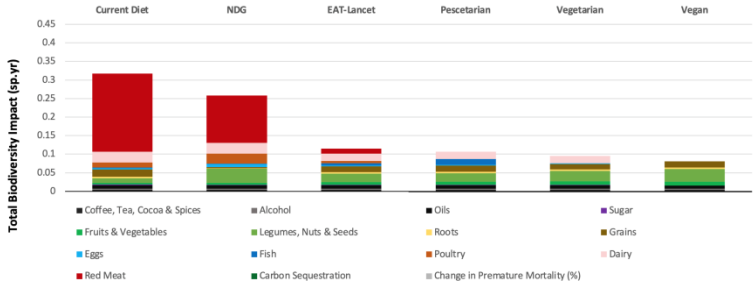

Figure 15. Number of total species expected to go extinct as a result of food production for current diets, NDGs, and other dietary patterns: Brazil.

However, dietary shifts may not always lead to reductions in biodiversity loss. For example, both India and Indonesia could potentially see increases in biodiversity loss with a shift to other dietary patterns. This is mainly due to recommended nutritional increases in the consumption of fruits, vegetables, dairy and oil (Figure 16 and 17) and less driven by red meat consumption as in other countries.

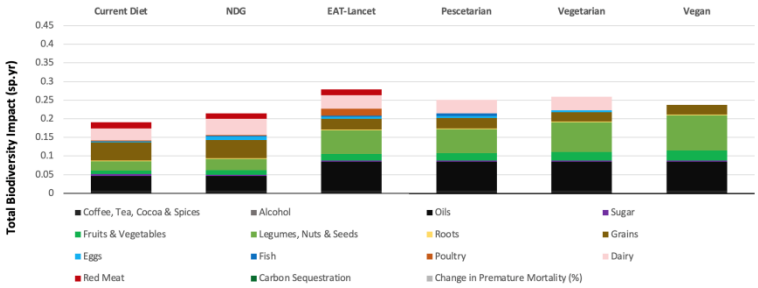

Figure 16. Number of total species expected to go extinct as a result of food production for current diets, NDGs, and other dietary patterns: India.

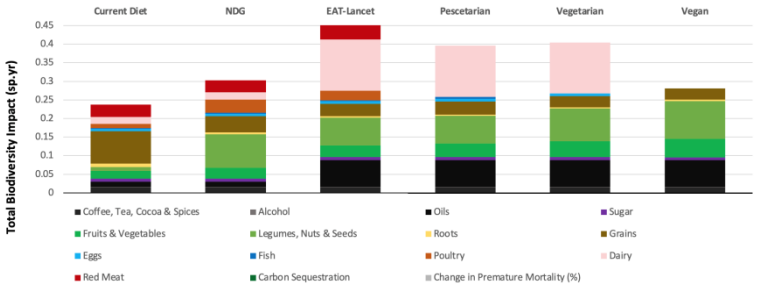

Figure 17. Number of total species expected to go extinct as a result of food production for current diets, NDGs, and other dietary patterns: Indonesia.

The increasing levels of biodiversity loss in both India and Indonesia are mainly driven by an increase in total food consumption of a variety of foods and in each country (g/day), which is needed to tackle under-nutrition.[31,32] Holding food production practices constant and assuming that food imports do not increase, our results show that this increase in total food consumption may require more agricultural land. These results, which only assess the impact of diets on biodiversity loss, highlight the critical importance of combining dietary shifts with more sustainable food production practices and reduced food loss and waste.[5]

The patterns here are similar to what we see in other tropical countries with high levels of biodiversity that would need to expand agricultural land to meet increasing levels of food consumption (see Figures 28 to 30 for more discussion on increased land use in Madagascar). Here and elsewhere throughout the report, this assumes that current food production practices are maintained, food loss and waste are not reduced, and food imports do not increase.

Although red meat and dairy consumption are the main global drivers of land conversion and biodiversity loss, the impact from other foods also needs to be carefully considered. In Denmark, for example, no decrease in biodiversity loss is seen with shifts toward diets with less animal-source products, because of increases in consumption of nuts, legumes and oils (Figure 18). In addition, the main driver of biodiversity loss in Danish diets comes from consumption of coffee, tea, cocoa and spices, most of which are imported from biodiversity-rich countries.

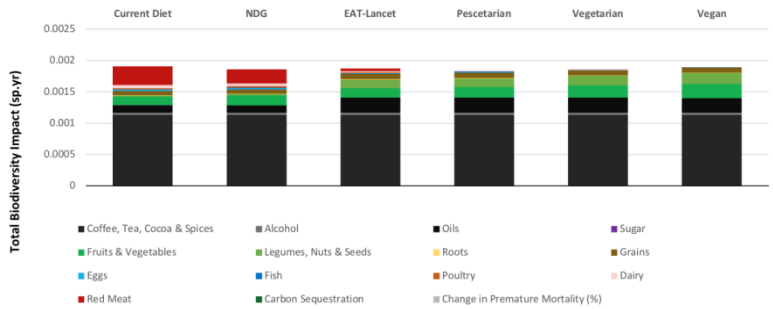

Figure 18. Number of total species expected to go extinct as a result of food production for current diets, NDGs, and other dietary patterns: Denmark.

The potential increase in biodiversity loss with increased consumption of foods would be further exacerbated if the additional demand on land was met solely by domestic production. Enhanced distribution and international trade of food could reduce land-use pressure and prevent biodiversity loss by increasing trade from higher-yielding and less biodiverse nations to lower-yielding and more biodiverse nations.[27] This is supported by research that shows that a rebalancing of regional production based on biodiversity concerns could mitigate additional stresses on land and that optimizing global land use based on biodiversity concerns could have the single greatest impact on reducing biodiversity loss.[5,19] International trade has also been promoted as a crucial means of achieving food security by increasing the availability and stability of the food supply at affordable prices.[33-36] For example, a recent analysis found that without liberalized trade, low-income countries in particular might find it difficult to meet their collective macro- and micro-nutrient needs.[37]

Takeaway: These results highlight the complex nature of dietary shifts and their impact on biodiversity loss at global, regional and national scales. At the global scale, dietary shifts are needed to reduce the dramatic decline in species. However, our results demonstrate that at the national scale, shifting toward healthier diets or increasing total caloric intake to tackle undernutrition without also reducing food loss and waste or improving food production practices could result in an increase in biodiversity loss in particular countries. These losses appear to be most dramatic in tropical countries, which are both the most biodiversity-rich countries on the planet and those most likely to suffer from undernutrition.

Strategic action 2: Living within the global carbon budget for food

What needs to happen – reduce total greenhouse gas emissions from food production to at most 5 Gt CO_2-eq.

Keeping global warming below 2°C and aiming for 1.5°C requires rapid decarbonization of all sectors by 2050.[1,38] This means halving global emissions every decade until 2050 while at the same time massively increasing carbon sinks to begin achieving negative emissions near mid-century (Figure 19).[39]

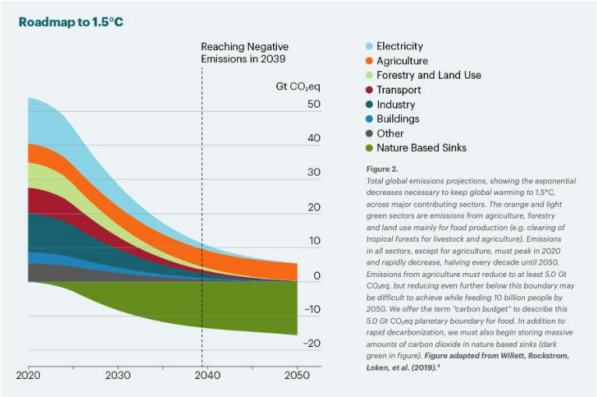

Figure 19. Total global emissions projections across major contributing sectors showing the exponential decreases necessary to keep global warming well below 2°C and aiming for 1.5°C. Emissions in all sectors, except for agriculture, must peak in 2020 and rapidly decrease, halving every decade until 2050. In addition to rapid decarbonization, massive amounts of carbon dioxide must be stored in nature-based sinks (dark green in figure). Source: Loken (2020).[14]

The food system is one of the main drivers for global GHG emissions[1,5] and accounts for roughly 27% (approximately 14Gt) of total emissions (approximately 53Gt) from all sectors. About two-thirds of all food-related GHG emissions are accounted for in the agriculture, forestry and land use sector (AFOLU), while the remaining third comes from processing, transport and packaging (Figure 20).[12,40]

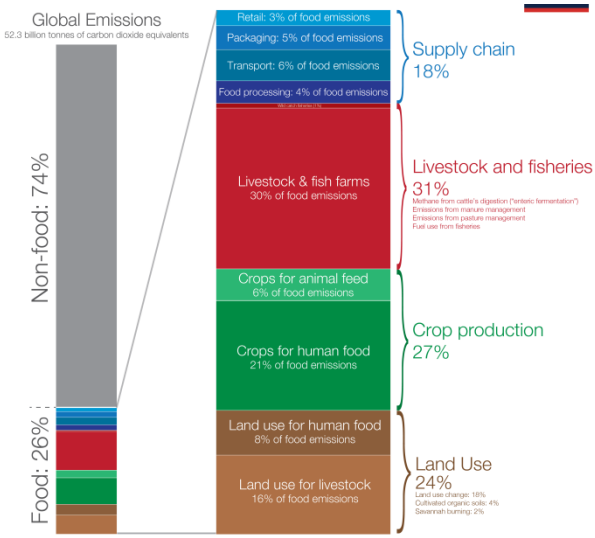

Figure 20. Major contributing sources to total emissions from food production. Source: Poore and Nemecek. (2018).[12]

However, while we can and must set high ambitions for anthropogenic GHG emissions reductions, not all of the 14Gt CO_2-eq from the food system can be eliminated by 2050. Some GHG emissions will always be generated because of biological processes that are intrinsic to crop (i.e. nitrous oxide from fertilizer use) and livestock production (i.e. methane from ruminants). To reflect this, the EAT-*Lancet* Commission on Food, Planet, Health sets a planetary boundary for food production emissions, or carbon budget, at a maximum of 5Gt CO_2-eq (total methane and nitrous oxide emissions).[5,14] The remaining 9Gt of emissions can, however, be mitigated through various activities including shifting diets, changes in food production practices, decarbonizing the food value chain, and reductions in food loss and waste.

Figure 21 below shows the global potential for reducing emissions by shifting diets. Following NDGs (data only from countries where NDGs are available) would only reduce the total food-related GHG emissions globally by around 1Gt, leaving 8Gt of emissions remaining (emissions gap) to get within the 5Gt carbon budget for food. Following a flexitarian diet would reduce total global food-related GHG emissions down to 9.9Gt, leaving an emissions gap of4.9 Gt. Only by universally following a vegan diet would GHG emissions be reduced to near the climate planetary boundary for food solely through a dietary shift. Any remaining emissions above this planetary boundary after dietary shifts would need to be mitigated through a combination of changes in food production practices and reductions in food loss and waste.

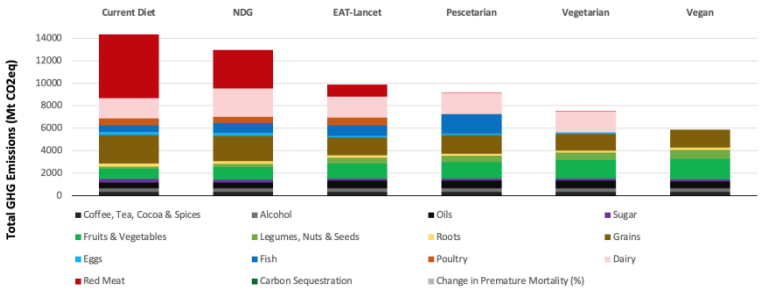

Figure 21. Total global GHG emissions through universal adoption of various dietary patterns including current average global diets and NDGs.

Most of the emissions reductions from shifting diets come from reductions in red meat and dairy consumption. Red meat and dairy currently account for just over half of total global food-related GHG emissions (7.4Gt of 14.3Gt). Shifting to a flexitarian diet would reduce these emissions to 2.9Gt, whereas more radical shifts in diets would reduce them to between zero and 1.9Gt globally (Figure 21). This would have the added benefit of reducing premature mortality rates in all countries.

However, dietary changes would be experienced differently depending on current consumption patterns in a country or region. Malawi, for example, is on course to meet global targets for under-five overweight and under-five wasting but is off course to meet targets for other indicators.[41] To address this, Malawi may need to increase consumption of certain food groups, including dairy, fish, and fruits and vegetables. This would lead to an increase in per capita GHG emissions of up to approximately 30% (Figure 22).

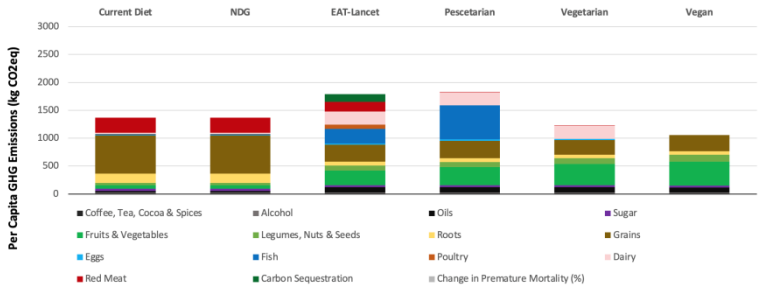

Figure 22. Per capita GHG emissions in Malawi for current diets, NDGs and other dietary patterns.

Sweden, on the other hand, would be able to nearly halve its emissions by adopting a flexitarian diet, mainly by decreasing overall red meat and dairy consumption (Figure 23). Doing so, however, would require a decrease in red meat consumption of nearly 90% (from 110g/day to 14g/day) and dairy of about 69% (from 940g/day to 290g/day). Following the NDGs would reduce per capita GHG emissions from food by approximately 30% but more ambitious reductions would still be needed.

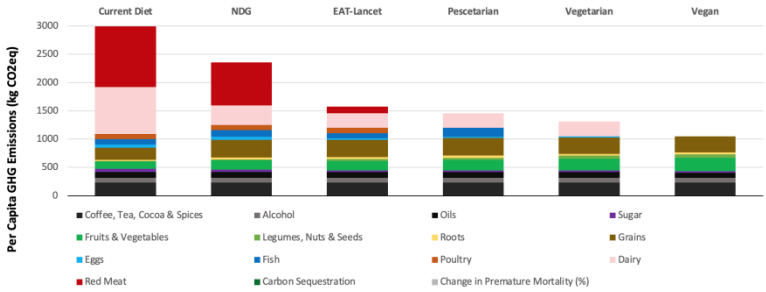

Figure 23. Per capita GHG emissions in Sweden for current diets, NDGs and other dietary patterns.

For all of us to live within the global carbon budget for food necessitates that we address the imbalance in global food-related emissions. Sweden's per capita food-related GHG emissions are more than double Malawi's, yet Malawi still faces significant burdens of undernutrition. To more equally share the global carbon budget for food will require more ambitious dietary shifts in some countries compared to others.[14] For example, Australia, Argentina, Brazil and France would need to reduce food-related emissions to a much greater degree than Bangladesh, Indonesia, and Ethiopia (Figure 24). A recent study found that, in particular, food consumption in G20 countries is unsustainable. Global adoption of current G20 food consumption patterns by 2050 would exceed the planetary boundary for food-related GHG emissions by 263% and would require up to seven Earths to support these patterns of food consumption. On average, food-related GHG emissions in G20 countries as a whole need to be approximately halved by 2050 to ensure we can feed 10 billion people healthy diets within planetary boundaries and enable a more equitable global distribution of food-related GHG emissions.[14]

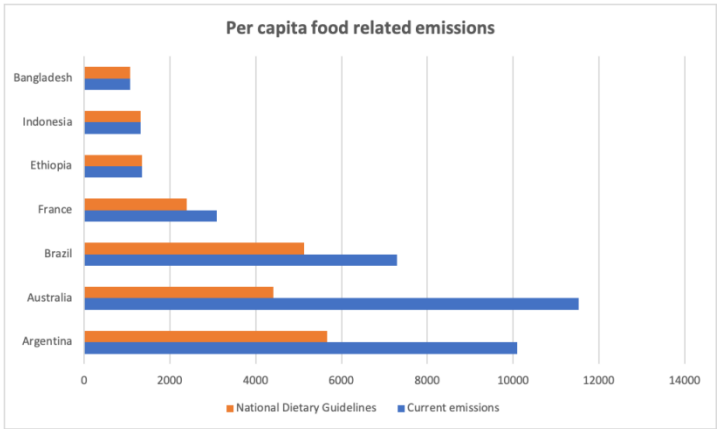

Figure 24. Per capita food-related GHG emissions in various countries for current consumption patterns and if NDGs were followed.

Takeaway: The trends described here highlight a dilemma in our food system: tackling all forms of malnutrition while keeping GHG emissions within the planetary boundary for food. Solving this dilemma requires a more equitable distribution of the global carbon budget for food to enable all countries to alleviate all forms of malnutrition while also tackling climate change. Countries should raise the ambition of their NDGs to align with international commitments such as the Paris Agreement, while ensuring that efforts to improve nutrition do not lead to the adoption of high-carbon diets.

Strategic action 3: Feeding humanity on existing cropland

What needs to happen – stop expansion of new cropland, or any agricultural land, at the expense of natural habitats, supplying future food demand on the same area of land as today (or ideally less).

Strategic actions 1 and 2 are centrally dependent upon land use. Land use has generally been considered a local environmental issue, but it is becoming a force of global importance and may be the single most pressing environmental issue of our day.[42] Currently agricultural land is the largest biome on Earth[12,43] and approximately 40% (~ 4.2 Bn ha) of all habitable land is used to feed humans (Figure 25). Of this, about 71% (3.0 Bn ha) is used for livestock grazing leaving roughly 29% (~ 1.2 Bn ha) to grow crops (Figure 26). Of this 1.2 Bn ha of arable land, 38% (460 M ha) is used to grow feed for livestock consumption (red meat, dairy and poultry).

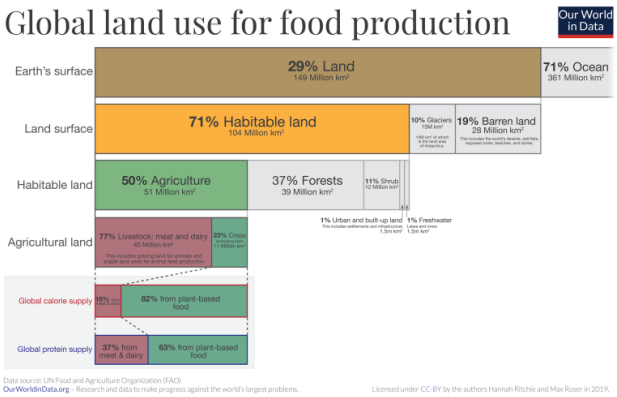

Figure 25. Total global land use for food production. PLACEHOLDER GRAPHIC FOR DESIGN INSPIRATION – To be updated based on above paragraph

Since the main drivers of biodiversity loss and GHG emissions from the AFOLU sector stem from land conversion, mainly for agriculture [20,27] we must halt expansion of new agricultural land at the expense of natural habitats to have any chance to reversing biodiversity loss and achieving the Paris Agreement. This means that humanity must be fed on the existing area of cropland.[5] Doing so, however, requires that instead of using nearly 40% of existing cropland to grow feed for livestock we use this nearly 460 M ha of arable land to grow food for human consumption (Figure 26).

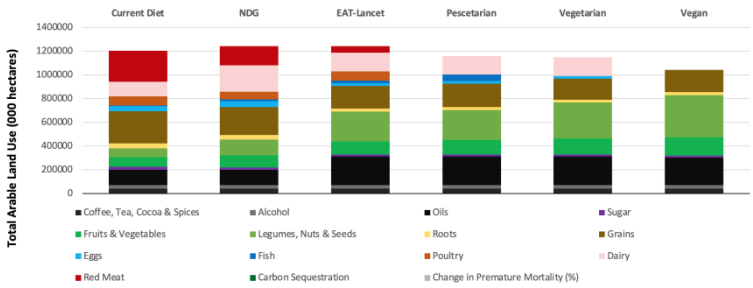

Figure 26. Total global cropland use for current diets, NDGs and other dietary patterns.

However, as seen in Figure 26, the net global impact of a reducing consumption of animal-source foods relative to plant-based foods would be at most only a slight decrease in total land used for crops. The reason dietary shifts alone do not free up much cropland is that any reduction in land used for livestock feed would instead need to be used to grow other crops, such as fruits and vegetables or nuts, legumes and seeds, all of which are more prevalent in the other dietary patterns assessed.

This does not mean, however, that dietary shifts are not important to halting the expansion of agriculture into natural habitats. Using limited arable land to produce crops for human consumption rather than animal feed will feed more people and provide more total calories.[44-46] Even so, feeding humanity on existing cropland will become increasingly difficult as the global population grows by nearly 2 billion people by 2050.[47] This emphasizes the urgent need to couple dietary shifts with improvements in food production practices and reductions in food loss and waste.

The addition of 2 billion more people on the planet will necessitate that nearly all the 1.2 Bn ha of cropland be used to grow crops for humans.[5,21] This could be done by adopting a 'livestock on leftovers' approach, which limits the availability of animal protein globally to what can be produced by raising animals on a) grassland unsuited to crop production (1/3 of global grazing lands is suitable for cropland)[48]; b) by-products arising from agricultural crop production; and c) food waste.[49] This would free up nearly 300 M ha of land that would have been reserved for livestock feed (poultry, dairy and red meat) under a flexitarian diet scenario (see Figure 26) and 450 M ha if NDGs were universally followed.

Although the total amount of cropland globally will remain nearly constant if we shift diets, individual countries could see drastic changes in the amount of cropland used to feed their citizens. In Canada, for example, arable cropland demand (both domestically and internationally) would be reduced by 36-47%, depending on the dietary pattern (Figure 27). This is mainly driven by a decrease in cropland used for livestock feed.

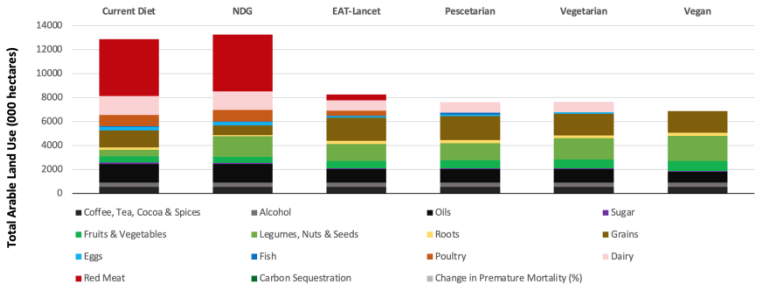

Figure 27. Total cropland use for current diets, NDGs and other dietary patterns: Canada.

On the other hand, in Madagascar adopting alternative dietary patterns could increase demand for cropland use by 39-48% (Figure 28). If this increase in demand for arable cropland is met by converting additional lands in the country instead of relying on improvements in food production practices, reductions in food loss and waste or changes in international trade, this could result in high rates of forest and biodiversity loss and increases in GHG emissions from land conversion. The main factor behind the increase in demand for cropland in Madagascar by adopting alternative dietary patterns is the large increase in daily food intake of nearly all food groups

(Figure 29) and a shift from the majority of food calories coming from rice (Figure 30) to a diversity of food groups.

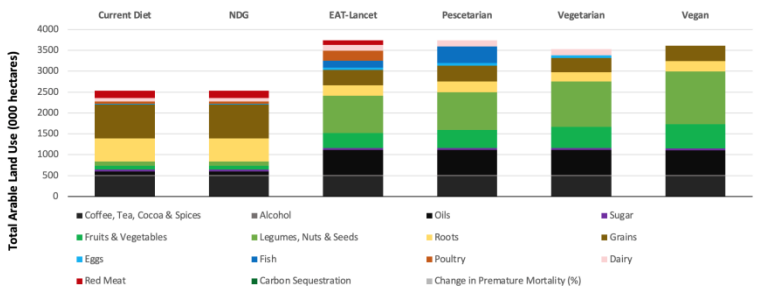

Figure 28. Total cropland use for current diets, NDGs and other dietary patterns: Madagascar.

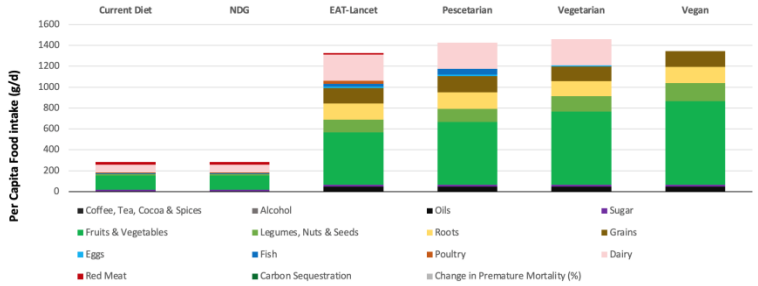

Figure 29. Per capita daily food intake (g/day) in Madagascar for current diets, NDGs, and other dietary patterns.

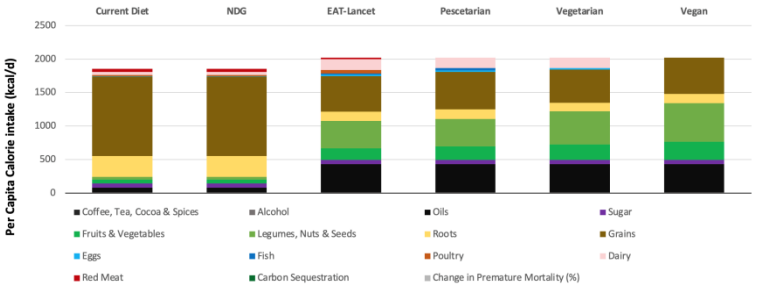

Figure 30. Per capita daily calorie intake by food group in Madagascar for current diets, NDGs and other dietary patterns.

Takeaway: Addressing the climate and biodiversity crises requires a halt in the expansion of new agricultural land at the expense of natural habitats. This can be achieved but requires that nearly all 1.2 Bn ha of cropland be used to grow crops for humans instead of feed for livestock. The addition of 2 billion more people on the planet will put even more strain on current croplands necessitating even greater urgency to reserve these lands to grow food for human consumption. Those countries that currently have high levels of food intake could see significant reductions in demand for cropland, while those countries that still experience an undernutrition burden could see an increase in demand for arable cropland. If this increase is met by converting additional lands in the country instead of relying on improvements in food production practices, reductions in food loss and waste or changes in international trade, this could result in high rates of forest and biodiversity loss and increases in GHG emissions from land conversion.

Strategic action 4: Achieving negative emissions

What needs to happen – move agriculture from a carbon source to a carbon sink, including freeing up existing agricultural lands that can be reforested or restored and rapid implementation of food production practices that increase carbon storage on agricultural land.

In the Paris Agreement, all countries pledged to keep total global temperature "well below" 2°C and to "pursue efforts to limit the temperature increase even further to 1.5°C". However, all options investigated by the Intergovernmental Panel on Climate Change (IPCC) for keeping the global temperature rise to well below 2°C require using "negative emissions" to remove massive amounts of CO_2 from the atmosphere and store it on land, underground, or in the oceans (see Figure 19).[50] A recent study that showed 1.5°C is also achievable, but only by using negative emissions.[51]

To achieve negative emissions, various methods are being discussed. A commonly proposed technology is bioenergy combined with carbon capture and storage (BECCS). BECCS realizes negative emissions by combining cultivation of plant biomass to pull CO_2 from the atmosphere, burning the biomass for energy in power plants, capturing the CO_2 released during combustion and then storing this in underground reservoirs. Full-scale implementation of BECCS is estimated to require a third of arable land.[52]

In addition to BECCS, tree planting has been widely promoted as a solution to climate change by absorbing and storing GHGs from the atmosphere.[53,54] It has been estimated that reforesting a billion hectares of land could store up to 205Gt of carbon – two-thirds of all the carbon released into the atmosphere since the Industrial Revolution.[55] World leaders have committed to restoring 350 million hectares of forest by 2030 and a "trillion tree" initiative has been launched.[56,57]

Large-scale implementation of BECCS and reforestation, however, could compete for both land and water needed for food production, as well as land needed for biodiversity.[52,58] Solving this paradox is centrally important to ensure that we can feed humanity while simultaneously achieving the Paris Agreement and restoring biodiversity.

Diets are key to successfully navigating these multiple and potentially competing agendas. In short, by eating more healthy and sustainable diets, our food system will require less agricultural land (mainly grazing lands), which could enable society to use land that was previously used for food production for other purposes (Figure 31). This general finding is not new. The IPCC's special reports on *Global Warming of 1.5ºC* [59] and *Climate Change and Land*[1] both highlighted the key need to reduce pressure on land through changes in food production and consumption.

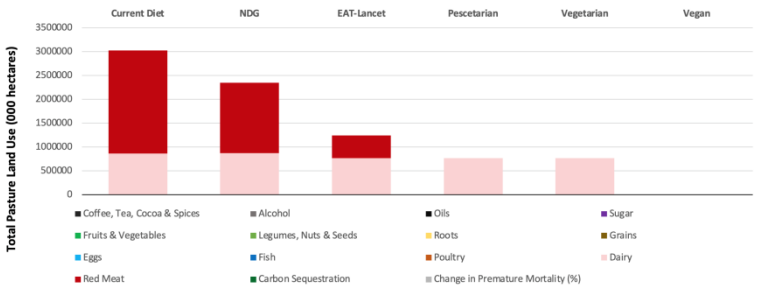

Figure 31. Total global area of grazing lands (pasture and rangelands) to support current diets, NDGs and other dietary patterns.

Because increasing consumption of plant-based foods relative to animal-source foods can free up land, it can theoretically enable more land to be available to restore nature (up to 3.0 Bn ha – see Figure 31), which will in turn sequester carbon as natural ecosystems return (only including reversion to native ecosystems – pre-agriculture). However, the magnitude of carbon sequestration from dietary shifts varies widely between countries. For example, a shift in diets in Denmark (Figure 32) would have lower per capita carbon sequestration potential than in Brazil (Figure 33).

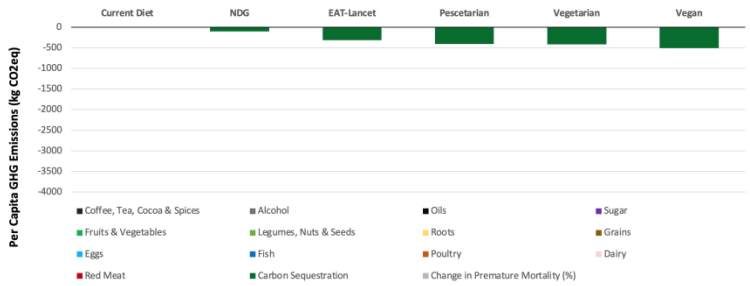

Figure 32. Per capita carbon sequestration for current diets, NDGs and other dietary patterns: Denmark.

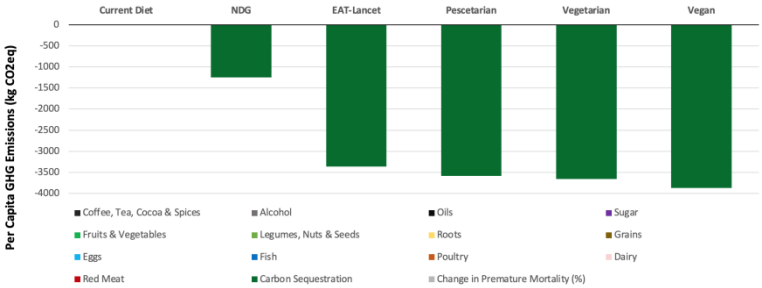

Figure 33. Per capita carbon sequestration for current diets, NDGs and other dietary patterns: Brazil.

This difference is driven not only by the foods that are eaten and how much land is needed to produce them (i.e. plant-based diets have lower land footprints), but also by where the food is produced and the strength of the carbon sinks in those regions. If a country imports food from a region with strong carbon sink potential, then dietary shifts would result in larger per capita carbon sequestration. This is important for individuals and policymakers in countries that want to account for the total net GHG emissions impact of their diet.

However, in our pursuit of achieving negative emissions, we must be careful not to drive more loss of grassland ecosystems. Some grazing lands are naturally occurring grasslands, savannahs and native prairies that are critically important ecosystems, rich in biodiversity and providing multiple ecosystem services. Other grazing lands have been converted from other ecosystems, including forests that have been cut down or burned to create livestock pasture.[60]

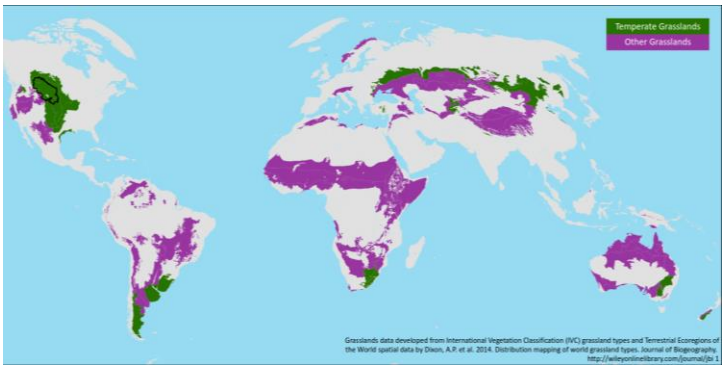

Figure 34. Naturally occurring grasslands of the world.

This analysis does not distinguish between rangelands and pastures due to a lack of resolution in the globally available data. However, we can draw some general conclusions from the results regarding the potential of carbon sequestration in various countries. For example, Brazilian diets use a total of approximately 173 M ha of pasture and rangeland to support current diets (Figure 35). Of this approximately 30% (48 M ha) was created through conversion of forest. A dietary shift to NDGs or alternative dietary patterns would free up millions of hectares of land, much of which could be restored back to tropical rainforest with massive carbon sink potential. However, as noted earlier, it is important that natural grassland ecosystems, such as the Cerrado, be preserved and reforestation efforts focus instead on restoring converted ecosystems to their pre-agriculture state.

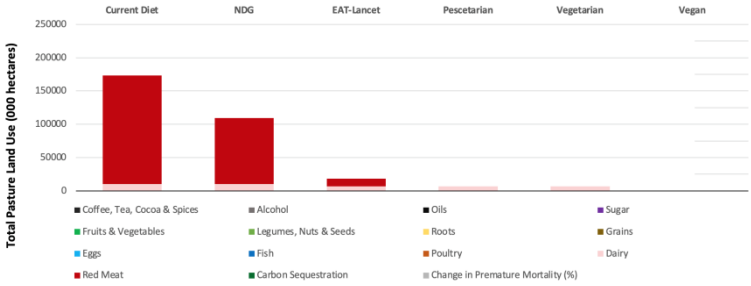

Figure 35. Total area of grazing lands (pasture and rangelands) needed to support current diets, NDGs and other dietary patterns: Brazil.

Removing livestock from rangelands could also result in destruction of native vegetation if done carelessly. For example, in the United States, approximately 250 M ha of grazing land is used to support current diets (Figure 36). Of this approximately 13% is pasture converted from other ecosystem types and 87% is rangelands.[61] A dietary shift toward NDGs or other dietary patterns could leave these grasslands vulnerable to conversion to crops for food or fuel. This could result in a net increase in GHG emissions and biodiversity loss from these systems.

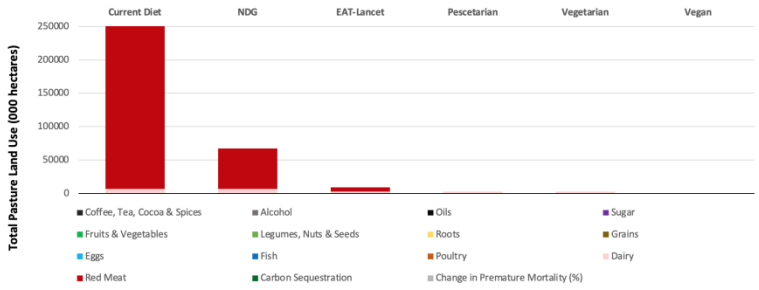

Figure 36. Total area of grazing lands (pasture and rangelands) to support current diets, NDGs and other dietary patterns: United States.

Not all countries, however, would see large reductions in rangelands and pastures with a shift in diets. In Ethiopia, for example, where livestock are used predominantly for dairy, a shift toward a flexitarian diet would only see a 10% reduction in grazing lands (Figure 37), while the same shift in Kenya would see a 20% reduction (Figure 38).

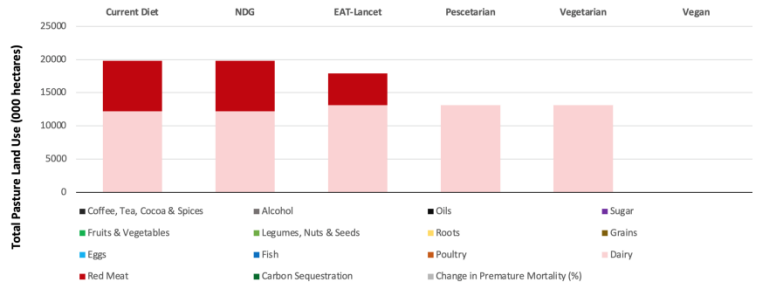

Figure 37. Total area of grazing lands (pasture and rangelands) to support current diets, NDGs and other dietary patterns: Ethiopia.

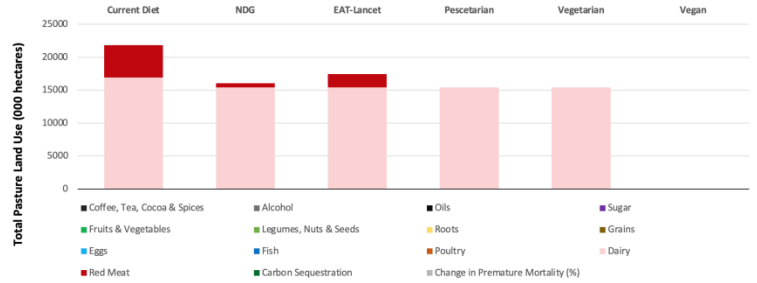

Figure 38. Total area of grazing lands (pasture and rangelands) to support current diets, NDGs and other dietary patterns: Kenya.

Takeaway: Carbon sequestration associated with dietary shifts can play a critical role in climate mitigation globally. Our results demonstrate that approximately 9Gt CO_2 can be sequestered per year through dietary shifts (Figure 39) that would free up agricultural land and allow for reversion to native ecosystems. Other studies have estimated the total global potential of carbon sequestration from dietary shifts to be between 332Gt (flexitarian diet) and 547Gt (vegan diet) of CO_2 by 2050, which is equivalent to 99-163% of the CO_2 emissions budget.[62] However, when looking for land to sequester carbon, it is important to carefully consider other ecosystem services and prevent the conversion of natural grasslands and savannahs and the loss of the flora and fauna that they support.[63,64]

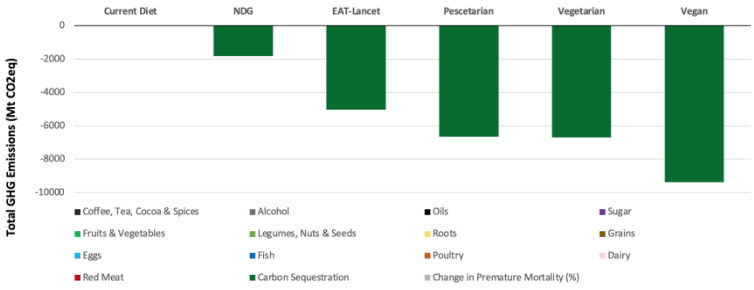

Figure 39. Total global carbon sequestration for current diets, NDGs and other dietary patterns.

Strategic action 5: Optimizing crop yields

What needs to happen – use all agricultural lands to their maximum potential including optimizing crop yields through better food production practices that more efficiently use water and fertilizers, preserve ecosystem functions and contribute to resilient landscapes.

To feed 10 billion people by 2050 while bending the curve on biodiversity loss and living within the global carbon budget for food, we will need to sustainably improve crop yields where possible to optimize production on all available land while also considering where key habitats can be restored (Figure 40).[5,19]

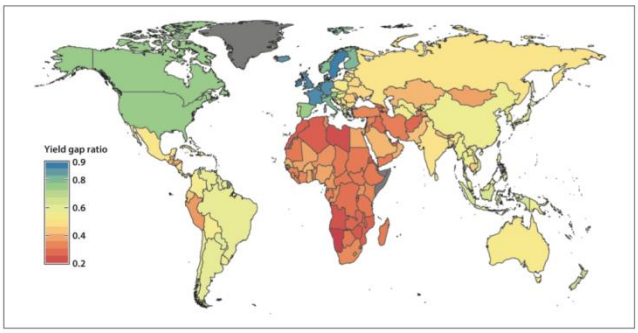

Figure 40. Yield gap ratios for various countries. Green and blue represents high yields and low yield gaps while countries in red and orange have high yield gaps. Source: Clark et al. (2018).[65]

This presents a dilemma, as increasing crop yields using a business-as-usual approach (i.e. no changes in how we currently produce food) would require additional inputs of water (from irrigation) and fertilizer, yet global freshwater resources are already under strain in many parts of the world (Figure 41) and nitrogen and phosphorus pollution already greatly exceed planetary boundaries (see Figure 4a). Excessive fertilizer application in food production has substantial consequences, notably in runoff into streams and rivers driving the eutrophication of freshwater and marine ecosystems and subsequent development of dead zones, causing fish dieback and other environmental harm.[66] Additionally, climate change will further increase challenges for water availability in many important agricultural regions, including more erratic precipitation and increased frequency of droughts. More intense rainfall events can increase the runoff of fertilizer into downstream water bodies.

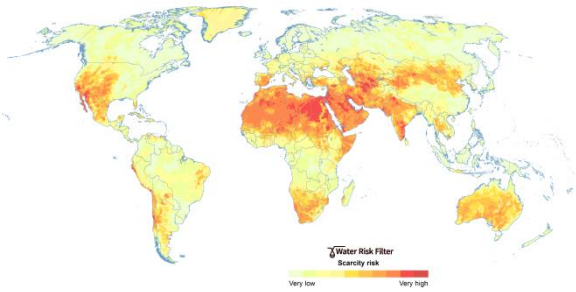

Figure 41. Water Risk Filter map showing the variation in water scarcity risk across the world, ranging from very high risk in dark red to very low risk in yellow/light green.[67]

This dilemma highlights the fact that feeding 10 billion people within planetary boundaries will require that we adopt significantly different methods of food production. Examples of agro-ecological methods include conservation agriculture, agroforestry and regenerative agriculture. These various farming practices all share the potential for high crop yields while reducing water and fertilizer inputs and enhancing the resilience of landscapes.[68] However, changes in food production practices alone will not be enough and dietary shifts will also be needed if we are to increase food production without further environmental damage.

Shifts in dietary choices do have the potential to influence how much water is used in various food production systems. For example, consider the potential reductions in water use in the United States and China, two of the most heavily irrigated countries. Our results show that increasing consumption of plant-based foods relative to animal-source foods, through a flexitarian diet, could reduce overall water use by up to 8% in the United States (Figure 42) and up to 15% in China (Figure 43), with much of that reduction coming from reduced consumption of mainly grain-fed meat and dairy livestock. This could potentially ease water use in already water-stressed regions around the world.

Across the United States, cattle-feed crops account for 23% of all water consumption; in the Colorado River basin, which is facing severe water shortages, it is over half.[69] However, translating a shift in diets to more sustainable water management, including making more water available to the environment, will require governance systems that can ensure water improvements are allocated to other beneficial uses.

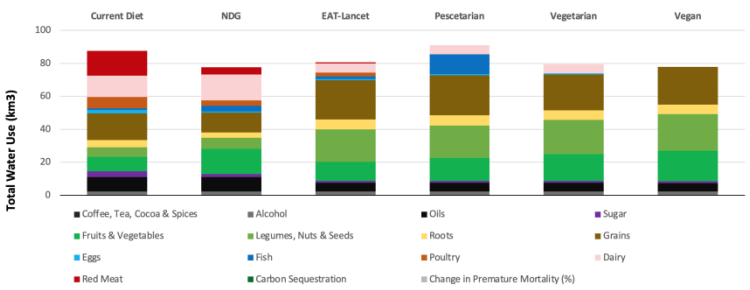

Figure 42. Total water use for current diets, NDGs and other dietary patterns: United States.

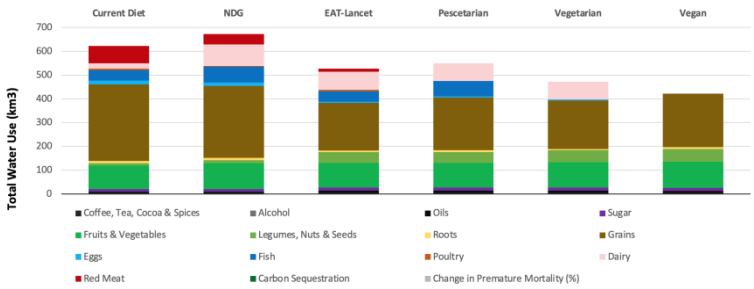

Figure 43. Total water use for current diets, NDGs and other dietary patterns: China.

Diets can also have a large impact on eutrophication potential, but this varies widely by country due to a number of factors – both in terms of *what* is grown and *how* it is grown. For example, in the United States a shift to vegetarian diets would lead to a two-thirds (67%) reduction in eutrophication potential from nitrogen and phosphorus pollution (Figure 44). This potential reduction would be driven largely by a reduction in red meat and dairy consumption and by the fact that much of the livestock in the United States is fed corn and soy that are grown using excessive amounts of fertilizer and on feedlots where nitrogen pollution from manure can leach into the environment.

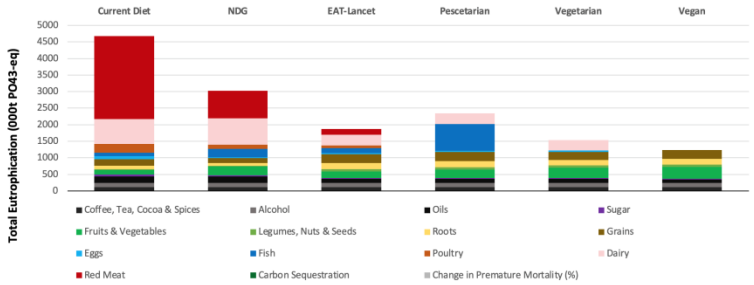

Figure 44. Total eutrophication potential from nitrogen and phosphorus use for current diets, NDGs and other dietary patterns: United States.

China, on the other hand, has higher levels of total eutrophication potential for current diets than the United States; this is driven more by aquaculture and grain production than by red meat and dairy (Figure 45). Following the NDGs in China could increase eutrophication potential, mainly from a recommended increase in consumption of fish from aquaculture and dairy. Most countries in the regions where nitrogen and phosphorus flows currently exceed the planetary boundary (e.g. United States, Western Europe, India and China) could see similar reductions in eutrophication potential with dietary shifts.

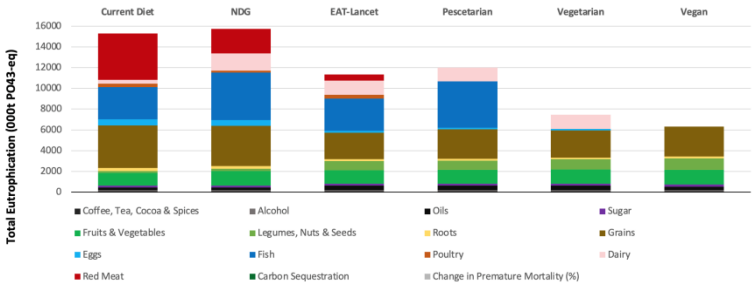

Figure 45. Total eutrophication potential from nitrogen and phosphorus use for current diets, NDGs and other dietary patterns: China.

Not all countries, however, would see a decrease in nitrogen and phosphorus pollution from a dietary shift. Zambia, for example, which is one of the largest aquaculture producers in Africa[70] and consumes a large proportion of farmed fish relative to caught fish, could see an increase in eutrophication potential for diets recommending higher intakes of fish (Figure 46). India could also see an increase in nitrogen and phosphorus pollution with an increase in fish consumption from aquaculture (Figure 47).

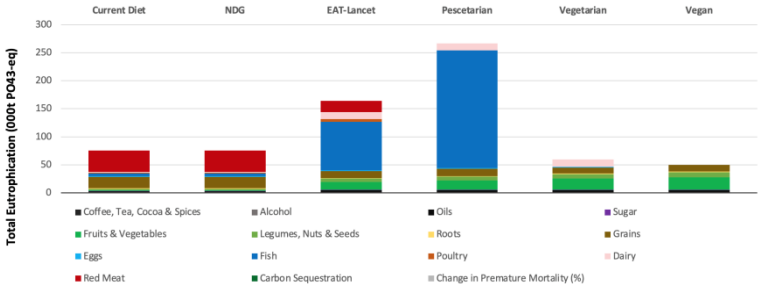

Figure 46. Total eutrophication potential from nitrogen and phosphorus use for current diets, NDGs and other dietary patterns: Zambia.

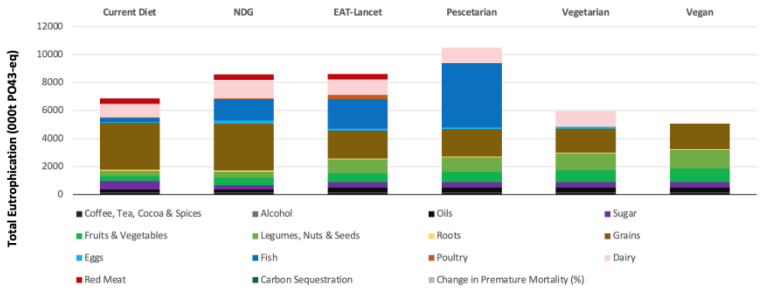

Figure 47. Total eutrophication potential from nitrogen and phosphorus use for current diets, NDGs and other dietary patterns: India.

Takeaway: These results highlight that dietary shifts can contribute to reducing water use and eutrophication potential in some countries. However, as with the other strategic actions, the impact will play out differently in various countries depending on the specific conditions that exist and the governance and practices in place that can translate potential reductions in water or fertilizer use into realized gains for water management and freshwater ecosystems. In addition, in some places that are already facing severe limitations on water availability or highly depleted soils, the international trade of food can help ease food security challenges, allowing countries and economies to overcome local water and soil limitations on their food supply. However, while easing food security in one country, trade can also exacerbate water and eutrophication problems in another, so a more holistic and globally coordinated response may be necessary.

POLICY RECOMMENDATIONS

Moving from a food system that exploits the planet to one that restores it for nature and people will take widespread, multi-sector, multi-level action. Although there is no magic 'fix', shifts toward planet-based diets are key to reversing the trends of habitat loss and degradation and species decline on a rapidly warming planet. However, as explored in this report, dietary shifts will look different and have widely varying impacts on countries' public health and environmental footprints, depending on the local-level realities and context. For that reason, we do not offer prescriptive policy advice specific to individual countries but instead offer more general but key recommendations for how to achieve the strategic actions outlined in this report.

National-level actions

Incorporate diets into nationally determined contributions (NDCs)

All countries that have signed the Paris Agreement are requested to revise and communicate their NDCs by the end of 2020 and every five years thereafter. This revision process provides important opportunities for governments to integrate goals for how the food system can assist with meeting their climate commitments. While many countries mention agriculture in their NDCs, very few set specific targets for mitigating climate change through food production and no countries mention sustainable diets in their NDCs.[71,72]

As outlined in this report, there are many opportunities for the food system to contribute to climate change mitigation and adaptation. The food system accounts for roughly 27% of global emissions and red meat and dairy production account roughly half of food-related emissions (7.4Gt of 14.3Gt). Our results show that universal adherence to NDGs would reduce food's emissions by 1.3Gt CO2eq per year and also lead to sequestration of 1.8Gt CO2 per year, which is approximately a 6% reduction in global GHG emissions. Shifting to a flexitarian diet would reduce emissions by 4.4Gt CO2eq per year and lead to 5Gt CO2 per year of sequestration, an 18% reduction in global GHG emissions while shifting to a vegan diet would reduce emissions by nearly 8.5Gt CO2eq per year and sequester nearly 9.4Gt CO2, a 34% reduction in total global GHG emissions. For those countries that still face significant burdens of undernutrition, the short-term potential of reducing emissions from dietary changes may be limited (see Figure 22) but there is still significant potential to reduce emissions by switching to more sustainable food production methods, halting land-use conversion for agriculture and reducing food loss and waste.

Commit to raising the ambition of national dietary guidelines (NDGs)

The findings of this report show that the NDGs of most countries will often only lead to a slight reduction of environmental impacts (see Figures 14, 21, 23) and in some cases may even lead to an increase in impacts (see Figures 13, 16, 27). These findings are supported by other studies that have shown that a large number of NDGs are incompatible with global health and environmental targets and few incorporate aspects of environmental sustainability.[11,13,14] Given this evidence, we believe that significant steps need to be taken to raise the level of ambition of NDGs in all countries to ensure they are in line with global health and environmental targets. We urge all countries to:

1. Immediately review and update existing NDGs or develop new NDGs that integrate human health and environmental sustainability goals.
2. Assign shared responsibility for updating existing NDGs to the Ministries of Health and Ministries of Environment or Agriculture, or their associated agencies.
3. Ensure updated NDGs are developed by an independent scientific body and are free from industry influence.
4. Integrate NDGs into environmental policy frameworks including the Paris Agreement, post-2020 global biodiversity framework and Sustainable Development Goals.

Initiate national-level multi-stakeholder dialogues on healthy and sustainable diets

To begin the process of transforming national food systems, we encourage policymakers to initiate national-level multi-stakeholder dialogues to discuss and explore the implications of implementing the five strategic actions outlined in this report. While government has a crucial role to play, the private sector and civil society must also be engaged to ensure that the full range of levers and capacities of experts in a country are used. We encourage all those involved in these dialogues to explore the full range of policy tools available (Table 2). Too often, attempts to change diet or other aspects of the food system rely too heavily on soft policy approaches, such as education campaigns, community empowerment initiatives or private sector voluntary commitments. Research demonstrates that harder policy tools, such as regulatory or fiscal measures, may be more effective in generating sustained change.[73]

Table 2. The various levels of policy options available to policymakers. Source: Nuffield Council on Bioethics[74]

Policy rung	*Policy option*	*Level of intervention*	*Description*
8	Eliminate choice	*'HARD'*	Channel actions only to the desired end and isolate inappropriate actions
7	Restrict choice		Remove inappropriate choice options
6	Guide choices through disincentives		Apply taxes or charges
5	Guide choices through incentives		Use regulations or financial incentives
4	Guide choice by changing default policy		Provide 'better' options
3	Enable choice		Enable individuals to change behaviour
2	Provide information		Inform or educate the public
1	Do nothing	*'SOFT'*	No action or only monitor situation

Curate the evidence base for your country

Although the global case is well established for the need to shift diets to achieve health and environmental goals,[1,3,5,11] extensive gaps remain (especially in low- and middle-income countries)[73] in the evidence base regarding specific implications of dietary shifts at the national level and which actions are most effective in a specific context. Most actions that have been implemented have aimed to improve health rather than environmental sustainability, yet as shown in this report, dietary shifts toward planet-based diets offer the opportunity for 'win-win' solutions.

To assist countries in curating their own evidence base, we have developed an online interactive modelling tool to accompany this report. This tool enables all interested stakeholders to determine national-level environmental and health impacts for various diets. The same type of results that are presented in this report can be tailored to a specific country or region. In addition, users are able to select daily or weekly intake levels of 13 food groups, with guidance on an optimal intake range for an average citizen, and see the results of these choices on various environmental and health indicators. A sample shopping basket of regionally specific food items is also offered to assist consumers when purchasing food.

Planet-Based Diets Impact & Action Calculator

Multilateral actions

Facilitate international coordination of efforts

Global transformations of the past have taught us that no single actor or breakthrough will be enough to catalyse systems change.[5] The results presented in this report have highlighted that transformational changes in the way we produce and consume food will require an unprecedented level of global partnerships and coordination of efforts. Although the specific actions that are implemented will be context-specific, the only way that we can bend the curve on the negative impacts of the global food system to achieve healthy and sustainable diets for all people is through coordinated global action.

The UN Food Systems Summit in 2021 is a critical opportunity to facilitate such international coordination. The UN Summit is intended to "*raise global awareness and land global commitments and actions that transform food systems to resolve not only hunger, but to reduce diet-related disease and heal the planet. The Secretary-General is calling for collective action of all citizens to radically change the way we produce, process, and consume food*."[75] The findings of this report can serve as a scientifically robust evidence base for the Summit to guide individual countries as they develop commitments to bend the curve on negative impacts of their own food systems.

Incorporate diets into the post-2020 global biodiversity framework

As the UN Decade on Biodiversity (2011–2020) and the Strategic Plan for Biodiversity 2011-2020 and its Aichi Targets draw to a close, there is a need for a more robust and binding commitment from all countries to slow down and reverse biodiversity loss. The post-2020 global biodiversity framework is currently being negotiated and will be agreed upon in 2021. The results of this study and many others have highlighted the critical role that shifting diets can play in reducing pressure on land conversion for agriculture and reversing biodiversity loss (see Figures 15, 27, 31).[1,5,27] With current food production accounting for nearly 80% of biodiversity loss globally (see Figure 12), the world will not be able to achieve progress on bending the curve on biodiversity loss unless dietary shifts are considered and incorporated into new treaties and agreements moving forward. Given this, we are calling for healthy and sustainable diets and their associated impacts to be integrated into the post-2020 global biodiversity framework. This could

be similar to how the IPCC's Special Report on Climate Change and Land[1] described plant-based diets as a major opportunity for mitigating and adapting to climate change – and included a policy recommendation to reduce meat consumption.[76]

Establish global research coordination bodies for food systems

Underlying any international coordination of efforts must be a champion or group of champions that highlights the narrowing gap between scientific evidence and policymaking. Such a group of champions for food systems and dietary shifts could be similar to existing bodies such as the IPCC, the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) or the International Panel of Experts on Sustainable Food Systems (IPES-Food). Currently, an integrated health and sustainable diets agenda tends to get lost or seen as too big to tackle and therefore a new oversight body or bodies might be needed that would be able to deliver robust scientific synthesis research while being subject to intergovernmental agreements, conventions and Conferences of the Parties (COP). An international body specifically focusing on healthy and sustainable diets, akin to how the IPCC focuses on climate change, could play a key role in curating the global evidence base necessary to build a global agenda on diets.

Develop a framework convention on food systems

As shown in this report, dietary changes can help to meet existing international agreements such as the Paris Agreement, global biodiversity framework and SDGs. However, a new framework convention or agreement/treaty for food systems is almost certainly needed to spur commitments and hold countries legally accountable to these commitments. A "UN Framework Convention on Healthy and Sustainable Food Systems", similar to the Framework Convention on Climate Change or the Convention on Biological Diversity, could help organize commitments but leave national-level strategies for transforming food systems up to individual countries. The agreements negotiated by such a framework convention on food would need to be informed by a scientific body of experts on healthy and sustainable diets, akin to the IPCC for climate change.

CONCLUSION

The 2020 *Living Planet Report* underlined how humanity's increasing destruction of nature is having catastrophic impacts not only on wildlife populations but also on human health and all aspects of our lives.[20] The message of this report, however, is not a lone beacon of warning. The scientific evidence to support nature's decline is unequivocal – it is being destroyed by us at a rate unprecedented in human history.

In recent years many studies have undertaken the task of determining the main drivers of the rapid destruction of nature and if it's still possible to reverse these trends.[5,19,21,77] The main conclusions from this growing body of research are that: 1) we still have time to reverse course and restore nature; 2) there are win-win solutions available today that are good for people and planet; and 3) what we eat matters.

In this report, we have shown the restorative power of planet-based diets and their potential to help individual countries achieve both environmental sustainability and human health goals. This presents us with a rare win-win opportunity that does not require new technologies – only a commitment from all nations to implement bolder, more ambitious NDGs and policies to ensure healthy planet-based diets for all citizens.

Diets by themselves, however, are not enough to bend the curve on the negative impacts of the global food system. To achieve this also requires bolder, more ambitious commitments to implement more sustainable food production practices. This includes amplifying national-level efforts to implement agro-ecological practices such as conservation agriculture, agroforestry and regenerative agriculture. When combined with reduced food loss and waste, we have a roadmap for restoring biodiversity and nature while feeding humanity.

Some may argue that warnings of the catastrophic impacts of the destruction of nature are alarmist. The human population has never been healthier and food has never been more plentiful. In addition, the human species has always advanced by exploiting the environment, so nature's destruction is inevitable and has in fact been positive and necessary for our species to thrive.

This argument is inherently flawed. The agricultural revolutions of the past have enabled humanity to feed more people and the rapid productivity gains since the "green revolution" have spurred improvements in human health and accelerated population growth.[18] These gains, however, have come at the expense of the environment; current global food production depends on practices that cross planetary boundaries, taking us into unknown and dangerous territory.[19] So far, increased food productivity has been able to stay ahead of the effects of a deteriorating environment – but this time lag has masked the underlying symptoms of a planet in crisis, and tricked us into believing that exploitation of the Earth's resources is without reckoning. Far from being alarmist, the dire warnings from the 2020 *Living Planet Report*, this report and many others show that there is now overwhelming scientific evidence that our past actions are catching up with us.

If the evidence clearly demonstrates that we can restore the planet and feed humanity, then why aren't we doing it? Three barriers have hindered action to date. First, the science has only recently advanced enough for us to fully understand the global impact of the food system. Second, the problem has yet to be broken down in sufficient detail for individual countries to understand their piece of the global jigsaw puzzle of building a food system that feeds humanity without destroying the planet. Third, humanity has never before needed to change the food system so radically at this scale or speed. The enormity of the task at hand can freeze individuals and policymakers and prevent them from taking action.

With this study we hope to advance the process of removing these three barriers so that action can be taken on the ground. Action on food system transformation must start at the local level, but before action can be taken, policymakers must understand the impacts on their country. Dietary shifts, which are a fundamentally important action that all countries must take to address both environmental and human health issues, will impact countries differently. Some countries will need to reduce their consumption of animal-source foods while others may need to increase them. Some countries may see GHG emissions decrease while others may see them increase.

Some countries will need to radically transform current diets while others may need instead to work to hold on to traditional dietary patterns and resist a transition to a more Western diet. All countries, however, will need to raise the ambition of their NDGs so that they are aligned with the latest science on human health and environmental sustainability to enable diets to help them achieve more ambitious NDCs, a holistic post-2020 global biodiversity framework, and a renewed commitment to the SDGs. The time for talk is over. It's now time to roll up our sleeves and get to work.

SCOPE, LIMITATIONS, UNCERTAINTY

Bending the Curve: The Restorative Power of Planet-Based Diets brings together scientists from across the WWF Network and from around the world to assess the impact of diets on various environmental and health indicators. Where possible, we have drawn on the expertise of leading scientists from a wide range of fields. The analyses used as the basis for this report have been previously published in leading journals such as the *British Medical Journal*[11] and *Science*.[12] We are confident in both the scientific rigor of the analysis and the conclusions drawn from it. We do, however, recognize that with all scientific studies limitations and uncertainty exist and therefore acknowledge some of these below.

To assess the impact of various food consumption patterns, we used a lifecycle assessment (LCA) approach. An advantage of using an LCA approach is that it enables a more complete and holistic understanding of the impact of food at all stages in its production. It also has several limitations. First, inconsistency in methodological choices makes comparisons across studies difficult. In this analysis, however, we use a source that substantially harmonizes across LCAs for methodological differences. Second, an LCA may only give an indication of the average environmental impact and may not give an indication of the best-case outcome. Third, LCA has historically focused on environmental not social impacts.[78] We fully acknowledge and recognize both the values and limitations of using an LCA approach; despite its limitations, important conclusions can still be drawn.

The estimates presented in this report are based on the best available science. However, given the limitations of LCAs, we acknowledge that uncertainty exists. In general, we have a higher level of scientific certainty about the overall direction and magnitude of the relationships described in this report but recognize that considerable uncertainty may exist around the specific quantifications presented throughout the report. We therefore encourage readers to focus more on the trends and relationships described and less on the precision and certainty of the quantifications presented.

Furthermore, we acknowledge that dietary patterns and food systems extend beyond environmental and human health impacts to include social, cultural, economic and animal welfare consequences and more. However, given the breadth of the topics discussed in the report, it was necessary to place many important economic and social issues out of its scope. These and other issues must eventually be considered and may best be done through multi-stakeholder dialogues and curation of a deeper evidence base for individual countries.

Although we focus mainly in the impact of diets, we fully acknowledge that to bend the curve on the negative impacts of a food system requires that dietary shifts be combined with ambitious improvements in food production practices and reductions in food loss and waste. Together, this will enable humanity to be fed healthy diets within planetary boundaries. We focus mainly on the impact of diets to be able to isolate their impact for decision-makers.

One environmental impact that was not able to be assessed was the impact of chemicals – i.e. pesticides and other substances that can be toxic to ecosystems and humans. We fully acknowledge that the use of chemicals for food production is a significant threat both to human health and environmental sustainability. We were not, however, able to assess their impact given the lack of scientific evidence available, which mean they cannot be included as part of an LCA.

Lastly, we did not explore future scenarios, which would be impacted by a multitude of variables including population growth, urbanization, and economic development. Instead, we offer a snapshot of current health and environmental impacts. For this we used a 2010 baseline population estimate of approximately 7.0 billion people. This is consistent with other studies and takes advantage of the most comprehensive data available.[5,21] When interpreting the results, however, it is important to keep in mind that an additional 2 billion people will need to be fed by 2050, making dietary shifts even more urgent.

LITERATURE CITED

1. IPCC. 2019. Climate Change and Land: an IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Intergovernmental Panel on Climate Change. www.ipcc.ch/srccl

2. IPBES. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany.

3. Global Nutrition Report. 2020. Action on equity to end malnutrition. Development Initiatives, Bristol, UK.

4. FAO, IFAD, UNICEF, WFP and WHO. 2020. The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. FAO, Rome, Italy.

5. Willett, W., Rockström, J., Loken, B., et al. 2019. Food in the Anthropocene: the EAT-*Lancet* Commission on healthy diets from sustainable food systems. *Lancet* 393:447–92.

6. FAO. 2020. COVID-19 and the risk to food supply chains: How to respond? FAO, Rome, Italy.

7. FAIRR. 2020. An industry infected: Animal agriculture in a post-COVID world. FAIRR initiative.

8. WWF. 2020. Covid-19: Urgent Call to Protect People and Nature. WWF.

9. UNEP and ILRI. 2020. Preventing the Next Pandemic: Zoonotic diseases and how to break the chain of transmission. United Nations Environment Programme, Nairobi, Kenya.

10. FOLU. 2019. Growing Better: Ten Critical Transitions to Transform Food and Land Use. Food and Land Use Coalition.

11. Springmann, M., Spajic, L., Clark, M.A. et al. 2020. The healthiness and sustainability of national and global food based dietary guidelines: modelling study. *BMJ* 370:m2322

12. Poore, J. and Nemecek, T. 2018. Reducing food's environmental impacts through producers and consumers. *Science* 360:987-992.

13. Gonzales Fischer, C. and Garnett, T. 2016. Plates, pyramids and planets: Developments in national healthy and sustainable dietary guidelines: a state of play assessment. FAO and Food Climate Research Network.

14. Loken, B. et al. 2020. Diets for a Better Future: Rebooting and Reimaging Food Systems in the G20. EAT, Oslo, Norway.

15. Godfray, C.J., Aveyard, P., Garnett, T., et al. 2018. Meat consumption, health, and the environment. *Science* 361(6399):eaam5324.

16. GLOPAN. 2016. Food systems and diets: facing the challenges of the 21st century. Global Panel, London.

17. Steffen, W., Richardson, K., Rockstrom, J., et al. 2015. Planetary boundaries: guiding human development on a changing planet. *Science* 347(6223).

18. Whitmee, S., Haines, A., Beyrer, C., et al. 2015. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. *Lancet* 386(10007):1973-2028.

19. Gerten, D., Heck, V., Jägermeyr, J., et al. 2020. Feeding ten billion people is possible within four terrestrial planetary boundaries. *Nature Sustainability* 3:200-208.

20. WWF. 2020. Living Planet Report 2020. Bending the curve of biodiversity loss. Almond, R.E.A., Grooten M. and Petersen, T. (eds). WWF, Gland, Switzerland.

21. Springmann, M., Clark, M., Mason-D'Croz, D., et al. 2018. Options for keeping the food system within environmental limits. *Nature* 562: 519-525.

22. FAO. Food-based dietary guidelines. www.fao.org/nutrition/education/food-dietary-guidelines/en (accessed 5 August 2020).

23. GBD 2017 Diet Collaborators. 2019. Health effects of dietary risks in 195 countries, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet, London, England.

24. FAO. 2019. The State of the World's Biodiversity for Food and Agriculture. Bélanger, J. and Pilling, D. (eds.). FAO Commission on Genetic Resources for Food and Agriculture Assessments. Rome, Italy.

25. Ceballos, G., Ehrlich, P.R. and Dirzo, R. 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. *PNAS* 114(30):e6089-96.

26. Pimm, S.L., Jenkins, C.N., Abell, R. et al. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. *Science* 344(6187):1246752.

27. Tilman, D., Clark, M., Williams, D.R. et al. 2017. Future threats to biodiversity and pathways to their prevention. *Nature* 546(7656):73.

28. WWF. 2017. Appetite for Destruction. WWF-UK, Woking, UK.

29. WRI. 2019. Creating a Sustainable Food Future: A Menu of Solutions to Feed Nearly 10 Billion People by 2050. World Resources Institute, Washington DC, USA.

30. Tilman, D. and Clark, M. 2014. Global diets link environmental sustainability and human health. *Nature* 515:518–22.

31. Global Nutrition Report. 2019. India nutrition profile. https://globalnutritionreport.org/resources/nutrition-profiles/asia/southern-asia/india (accessed 6 August 2020).

32. Global Nutrition Report. 2019. Indonesia nutrition profile. https://globalnutritionreport.org/resources/nutrition-profiles/asia/south-eastern-asia/indonesia (accessed 6 August 2020).

33. Clapp, J. 2015. Food security and international trade: unpacking disputed narratives. Background paper prepared for The State of Agricultural Commodity Markets. FAO, Rome, Italy.

34. OECD. 2013. The role of food and agricultural trade in ensuring domestic food availability. In: Global food security: challenges for the food and agricultural system. OECD, Paris, France.

35. Gillson, I. and Fouad, A. 2015. Trade policy and food security: improving access to food in developing countries in the wake of high world prices. World Bank, Washington DC, USA.

36. Brooks, J. and Matthews, A. 2015. Trade dimensions of food security. OECD Food, Agriculture and Fisheries Papers, No. 77. OECD Publishing, Paris, France.

37. Wood, S.A., Smith, M.R., Fanzo, J., et al. 2018. Trade and the equitability of global food nutrient distribution. *Nature Sustainability* 1(1):34-7

38. Rockström, J., Gaffney, O., Rogelj, J. et al. 2017. A roadmap for rapid decarbonization. *Science* 355(6331):1269-1271.

39. Falk, J., Gaffney, O., Bhowmik, A.K. et al. 2019. Exponential Roadmap 1.5. Future Earth, Sweden.

40. Smith, P., Bustamante, M., Ahammad, H., 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. Cambridge University Press, Cambridge, UK and New York, NY, USA.

41. Global Nutrition Report. 2019. Malawi nutrition profile. https://globalnutritionreport.org/resources/nutrition-profiles/africa/eastern-africa/malawi (accessed 5 August 2020).

42. Foley, J.A., DeFries, R., Asner, G.P. et al. 2005. Global consequences of land use. *Science* 309(5734):570-574.

43. Ramankutty, N., Mehrabi, Z., Waha, K. et al. 2018. Trends in global agricultural land use: Implications for environmental health and food security. *Annual Review of Plant Biology* 69:789-815.

44. Ranganathan, J., Vennard, D., Waite, R., et al. 2016. Shifting diets for a sustainable food future. World Resources Institute, Washington DC, USA.

45. Shepon, A., Eshel, G., Noor, E. and Milo, R. 2018. The opportunity cost of animal based diets exceeds all food losses. *PNAS* 115(15):3804-3809.

46. Harwatt, H. and Hayek, M.N. 2019. Eating away at climate change with negative emissions: Repurposing UK agricultural land to meet climate goals. Harvard Law School.

47. UN Population Division. 2019. World Population Prospects 2019. Population Division of the UN Department of Economic and Social Affairs. https://population.un.org/wpp (accessed 6 August 2020).

48. Garnett, T., Godde, C., Muller, A. et al. 2017. Grazed and confused. FCRN. Oxford Martin Programme on the Future of Food. University of Oxford, UK.

49. Röös, E., Bajzelj, B., Smith, P. et al. 2017. Greedy or needy? Land use and climate of food in 2050 under different livestock future. *Global Environmental Change* 47:1-12.

50. Gasser, T., Guivarch, C., Tachiiri, K., Jones, C. and Ciais, P. 2015. Negative emissions physically needed to keep global warming below 2 C. *Nature Communications* 6:7958.

51. Rogelj, J., Popp, A., Calvin, K.V. et al. 2018. Scenarios towards limiting global mean temperature increase below 1.5° C. *Nature Climate Change* 8:325-332.

52. Smith, P., Davis, S.J., Creutzig, F. et al. 2016. Biophysical and economic limits to negative CO_2 emissions. *Nature Climate Change* 6(1):42-50.

53. Williamson, P. 2016. Scrutinize CO_2 removal methods: the viability and environmental risks of removing carbon dioxide from the air must be assessed if we are to achieve the Paris goals. *Nature* 530(7589): 153-6.

54. Griscom, B.W., Adams, J., Ellis, P.W. et al. 2017. Natural climate solutions. *PNAS* 114(44):11645-11650.

55. Bastin, J.F. Finegold, Y., Garcia, C. et al. 2019. The global tree restoration potential. *Science* 365(6448):76-79.

56. The Bonn Challenge. www.bonnchallenge.org (accessed 7 August 2020).

57. Trillion Trees. www.trilliontrees.org (accessed 7 August 2020).

58. Brack, D. and King, R. 2020. Managing land-based CDR: BECCS, forests and carbon sequestration. *Global Policy*. https://doi.org/10.1111/1758-5899.12827

59. IPCC. 2018. Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

60. Curtis, P.G., Slay, C.M., Harris, N.L. et al. 2018. Classifying drivers of global forest loss. *Science* 361:1108-1111

61. USDA. Natural Resource Conservation Service. Rangelands - www.nrcs.usda.gov/wps/portal/nrcs/main/national/landuse/rangepasture/range and Pasture Resources - www.nrcs.usda.gov/wps/portal/nrcs/main/national/landuse/rangepasture/pasture (accessed 19 September 2020).

62. Hayek, M.N., Harwatt, H., Ripple, W.J. and Mueller, N.D. 2020. The carbon opportunity cost of animal-sourced food production on land. *Nature Sustainability*. https://doi.org/10.1038/s41893-020-00603-4

63. Chazdon, R.L. and Laestadius, L. 2016. Forest and landscape restoration: Toward a shared vision and vocabulary. *American Journal of Botany* 103:1869-1871.

64. Veldman, J.W., Silveira, F.A.O., Fleischman F.D. et al. 2017. Grassy biomes: An inconvenient reality for large-scale forest restoration? A comment on the essay by Chazdon and Laestadius. *American Journal of Botany* 104:649-651.

65. Clark, M., Hill, J. and Tilman, D. 2018. The diet, health, and environment trilemma. *Annual Review of Environment and Resources* 43:109-134.

66. Diaz, R.J. and Rosenberg, R. 2008. Spreading dead zones and consequences for marine ecosystems. *Science* 321(5891):926-9.

67. Water Risk Filter. waterriskfilter.panda.org (accessed 23 September 2020).

68. FAO. 2018. Transition toward sustainable food and agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy.

69. Richter, B.D., Bartak, D., Caldwell, P. et al. 2020. Water scarcity and fish imperilment driven by beef production. *Nature* 3:319-328.

70. FAO. Zambia: National Aquaculture Sector Overview. www.fao.org/fishery/countrysector/naso_zambia/en (accessed 8 August 2020).

71. WWF. 2020. Enhancing NDCs for food systems: Recommendations for decision makers. WWF-Germany and WWF Food Practice.

72. Tirado, M.C. 2019. Sustainable and healthy dietary patterns addressing climate mitigation while promoting health. Talanoa Dialogue. UNFCCC.

73. Garnett, T., Mathewson, S., Angelides, P. and Borthwick, F. 2015. Policies and actions to shift eating patterns: what works? Food Climate Research Network, Chatham House, London, UK.

74. Nuffield Council on Bioethics. 2007. Public health: ethical issues. Cambridge Publishers / Nuffield Council on Bioethics, Cambridge UK. nuffieldbioethics.org/project/public-health

75. United Nations. Food Systems Summit 2021. www.un.org/sustainabledevelopment/food-systems-summit-2021 (accessed 5 September 2020).

76. Schiermeier, Q. 2019. Eat less meat: UN climate-change report call for change to human diet. www.nature.com/articles/d41586-019-02409-7 (accessed 5 September 2020).

77. Leclère, D., Obersteiner, M., Barrett, M et al. 2020. Bending the curve of terrestrial biodiversity needs and integrated strategy. *Nature*. https://doi.org/10.1038/s41586-020-2705-y

78. Food Source. The value and limitations of life-cycle assessment. foodsource.org.uk/book/export/html/32 (accessed 6 September 2020).