

SUSTAINABLE AND NUTRITION-SENSITIVE FOOD SYSTEMS: THE PLANETARY BOUNDARIES APPROACH

Özge Geyik

Summary

Nutrition transcends sectors and, hence, requires multi-sectoral action. On the way to the first ever United Nations Food Systems Summit, which will take place in September 2021, actors from non-governmental, governmental, and the private sectors are engaging in joint efforts to facilitate discussions on pathways for food systems transformation. Globally, food systems are failing to address the multiple roles outlined in the Sustainable Development Goals. The cost of the triple burden of malnutrition—the coexistence of hunger, overnutrition, and hidden hunger—is increasing worldwide. At the same time, food systems activities are putting immense pressure on many Earth-system processes such as climate, land, and freshwater systems in addition to biogeochemical cycles and biosphere integrity. Fair, sustainable, and healthy food environments are prerequisites to achieve food and nutrition security. Hence, food system transformation is indispensable to secure affordable and nutritious food for all within the planetary boundaries.

About the Istanbul Policy Center-Sabanci University-Stiftung Mercator Initiative

The Istanbul Policy Center–Sabancı University–Stiftung Mercator Initiative aims to strengthen the academic, political, and social ties between Turkey and Germany as well as Turkey and Europe. The Initiative is based on the premise that the acquisition of knowledge and the exchange of people and ideas are preconditions for meeting the challenges of an increasingly globalized world in the 21st century. The Initiative focuses on two areas of cooperation, EU/German-Turkish relations and climate change, which are of essential importance for the future of Turkey and Germany within a larger European and global context.

What are food systems and why do they matter?

The Sustainable Development Goals (SDGs), which were set by the member states of the United Nations (UN) in 2015, proceeded the Millennium Development Goals in recognizing that extensive intersectoral and interinstitutional collaboration is needed among the environmental, social, and economic domains. Goals like No Poverty (SDG1), Zero Hunger (SDG2), Responsible Consumption and Production (SDG12), and Climate Action (SDG13) defined explicit targets and indicators that are inextricably intertwined. SDG2 calls for increased capacity for climate change adaptation to ensure sustainable and resilient food systems, while SDG13 cautions against potential threats to food production as a result of a lack of integrated policies and measures to combat climate change.¹ Similarly, SDG1 emphasizes the importance of resilience to climate-related events or shocks from other causes. SDG12, on the other hand, demands halving food waste and reducing the material footprint per unit of gross domestic production. Overall, food systems, which are social-ecological systems consisting of biophysical (e.g., climate and soil), social (e.g., cultural norms, entitlements, and socio-economic factors), and political factors (e.g., policies and incentives) are at the core of all dimensions of sustainability (see Figure 1).

More and more people around the world have been experiencing the so-called *nutrition transition*, which refers to major shifts in the human diet, activity patterns, and corresponding nutritional and health outcomes.² In broad terms, the nutrition transition model encompasses five temporal stages throughout human history³:

- 1 | The Paleolithic Era: hunter-gatherer forms of collecting food; diets are high in fiber and carbohydrates and low in fat (e.g., saturated fat), labor-intensive work and leisure
- 2 | Famines: acute food scarcity and low diversity in diets, dominance of starchy staples, undernutrition, and increased social stratification, labor-intensive work and leisure
- 3 | Receding famine: increased consumption of fruits, vegetables, and animal food sources, high fiber and low fat intake, low diversity in diets, labor-intensive work and leisure start to shift toward inactivity
- 4 | Dietary patterns linked with diet-related non-communicable diseases (NCDs) (*the nutrition transition*): increased consumption of fats (e.g., hydrogenated fats), sweeteners, and reduced fiber intake as a result of a larger share of refined carbohydrates and processed foods in diets, shift in work and leisure to sedentary lifestyles
- 5 | Behavioral change: desire to prevent or delay degenerative diseases and aging, reduced fat intake, increased vegetable, fruit, fiber intake, and activity levels

What the literature as well as this policy brief refer to as *the nutrition transition* is the fourth stage of the nutrition model. Associated shifts in diets and activity levels have been experienced by countries from all income levels and segments of the population, although not everyone has the same experience.⁴ The nutrition transition has also been accompanied by two other major processes of change: the demographic transition and the epidemiological transition. The former is described as a shift in population dynamics from those typically of low prosperity, high fertility and mortality toward patterns of high prosperity, low fertility and mortality.⁵ The latter is defined as the changes in health and disease patterns, such as the change in disease patterns from infectious to those resulting from complex interactions among demographic and socio-economic determinants.⁶

The underlying drivers of changes in dietary patterns as part of the nutrition transition are manifold: increasing per capita incomes, urbanization, social (e.g., information flows and economic globalization including international trade, foreign direct investment, transnational food companies), agricultural policies, education, maternal and child-care services, advertising, technology and innovation, food processing, and culture are among the main drivers.

The year 2020 marked the midterm of the UN Decade of Action on Nutrition 2016–2025, which

represents UN member states' commitment to accelerated and coordinated action to achieve nutrition-related targets set out in the 2030 agenda for Sustainable Development. However, the global community is nowhere near on track to achieve nutritional goals by 2030 as specified in SDG2 Zero Hunger. The triple burden of malnutrition, which refers to the coexistence of hunger (not enough calories), overnutrition (prevalence of overweight/obesity as a result of too many calories), and hidden hunger (micronutrient deficiencies such as iron, Vitamin A, or zinc deficiencies), continues to grow. The global burden of malnutrition is estimated to cost world economies 3.5 trillion USD per year, while maternal and child malnutrition is responsible for more than 10% of the global burden of disease. Being overweight or obese, on the other hand, leads to the deaths of 2.6 million people each year.⁷ The nutrition transition has unfolded

COVID-19 AND FOOD SYSTEMS

The ongoing COVID-19 pandemic has highlighted many of the vulnerabilities in our food systems. Long-lasting lockdowns and restrictions have impaired several supply chain activities from production to distribution. As a result, many people in urban settings have faced difficulties accessing fresh food, particularly during the initial months of the pandemic. Millions have lost their incomes and/or experienced lower purchasing power. At the same time, perishable food that could not make its way to the markets was wasted. On top of the pandemic, other disasters have exacerbated food and nutrition insecurity across the world, including floods in China, Sudan, Yemen, and Nepal; cyclones in India and Bangladesh; droughts in Zimbabwe, Turkey, and Chile; wildfires in Brazil, Siberia, and the United States; and devastating locust plagues across Africa, the Middle East, and South Asia. Post-pandemic recovery processes should take the opportunity to “build back better” and transform food systems toward those that are nutrition-sensitive, sustainable, and resilient to pandemics.

In 2019, the Secretary General of the United Nations announced a Food Systems Summit, drawing attention to the urgency of food systems transformation to get on track with achieving the SDGs. Since then, numerous stakeholders from a wide variety of sectors including non-governmental organizations, governmental institutions, farmers, scientists, and private sector have engaged in the so-called Food Systems Dialogue to facilitate an inclusive discussion around the type of transformation needed.

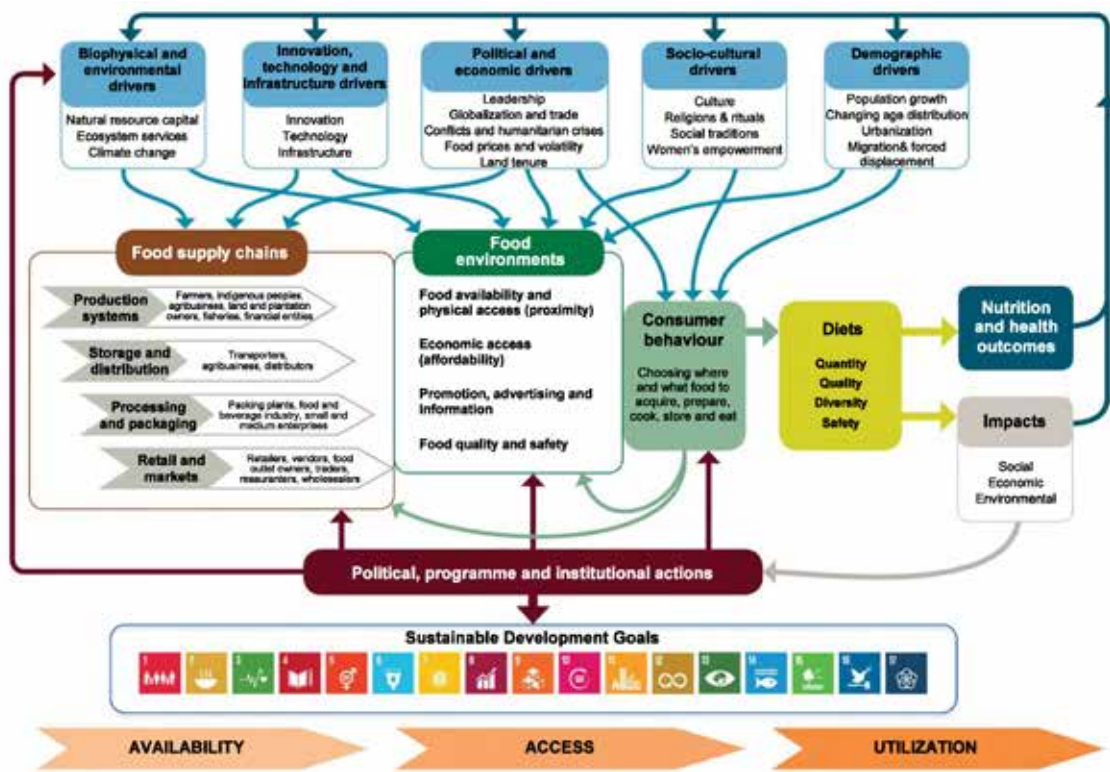
differently in different contexts. As of 2019, more than 690 million people—approximately 9% of the global population—went hungry (e.g., not enough calorie intake)⁸ whereas around 3 billion people suffered from at least one form of malnutrition.⁹ As incomes grow, the nutrition transition has occurred faster in the developing world than in high-income countries. Furthermore, the burden of malnutrition shifts to the poor in low- and middle-income countries. It is suggested that being of a lower socioeconomic status is a systematic risk factor for obesity in upper-middle-income countries such as Turkey.¹⁰

As the world has been changing and rapidly globalizing, issues around the agri-food sector have become more complex and interconnected. This

FOOD SECURITY VERSUS FOOD SAFETY

In Turkey, confusion around the definition and usage of food security and food safety still exists. Although the two are related concepts for human nutrition, they are different. Food security is a measure of having regular physical, social, and economic access to sufficient, safe, and nutritious food to meet one's dietary needs and food preferences for an active and healthy life. In this regard, food security presupposes access to safe food. Food safety is concerned with handling, storing, and preparing food to prevent infection and food-borne illnesses.

Figure 1: Graphical abstract of the food systems framework.¹²



requires a systems thinking approach to address such issues in a holistic manner. In this regard, the food systems framework serves as an interdisciplinary lens through which the multifaceted role those systems play can be analyzed coherently. Food systems represent the network of interconnected elements and entail all activities, people, and institutions that result in food security outcomes across all dimensions such as availability, access, and utilization¹¹ in addition to other social, economic, and environmental outcomes including culture, employment, and pollution and greenhouse gas emissions as well as biodiversity loss, among others.

Typology of food systems

We can categorize local food systems into five groups based on their level of development and scale:

- 1 | **Rural and traditional:** dominated by smallholders, typical of low yields, production consists mostly of staple crops with some additional cash crops, short

supply chains and small contribution by imported foods, large seasonal price swings, informal food markets and street vendors, a significant number of countries adopt voluntary or mandatory guidelines for fortification in staple foods to alleviate micronutrient deficiencies that result from low dietary diversity, supermarkets are not common outside of capitals

- 2 | **Informal and expanding:** higher input (e.g., fertilizer and seeds) use and higher agricultural productivity compared to rural and traditional systems, medium- and large-scale (to a smaller extent) farms, traditional supply chains and informal markets dominate fresh food access, insufficient cold chain infrastructure, modern supply chains exist for grains and dry food, supermarkets and fast food stores are expanding and processed/packaged foods are present in both urban and rural areas, as in rural and traditional food systems many countries have fortification guidelines

- 3 | **Emerging and diversifying:** medium-, large- and small-scale farms coexist, modern supply chains for fresh foods are rapidly developing, longer supply chains and a larger volume of imported food, processed/packaged foods are more accessible in rural areas, smaller seasonal swings in prices and supply, supermarkets are more common and their market shares increasing, informal markets still dominate fresh food access, food safety and quality standards apply for formal markets, many countries have food-based dietary guidelines
- 4 | **Modernizing and formalizing:** agricultural productivity is higher, mechanization and input-intensive practices in large-scale farms, food losses decrease as food waste increases, more diverse diets year-round as a result of food imports, low-income households are more likely to use supermarkets and other modern retail stores, food safety and quality monitoring is more common, food labeling imposed for ultra-processed foods
- 5 | **Industrialized and consolidated:** farming has a small contribution to national economies, large-scale and input-intensive farms contribute to domestic and international markets, long supply chains consist of local and international foods, urban areas have high supermarket density and only small towns may lack supermarkets, fresh food accessed through formal markets, luxury food retailers expanding, several countries have policies to regulate added industrial trans fats and salt

Overall, beyond supply chains, which type of food system is present has a reciprocal relationship with the food environment in which a certain population makes decisions on food consumption. Food environments in human societies characterize the physical, economic, political, and cultural contexts that determine food availability, affordability, properties, and messaging and retail properties.¹³ Availability of diverse food sources is a crucial requirement that may not always be secured by domestic sources.¹⁴ Furthermore, geography and infrastructure may constrain food availability via distribu-

tion, particularly for perishable products such as fresh fruits and vegetables and unprocessed animal products. Affordability remains a substantial challenge for many who cannot afford nutrient-dense food such as fruits and vegetables and animal source foods.¹⁵ Those food groups are often priced several times higher (up to 10 times higher for dairy and eggs in low-income countries) than starchy staple foods (e.g., rice, maize, wheat, and potatoes).¹⁶ Nevertheless, it is worth noting that such estimates are on a calorie-by-calorie basis, and people do not often require large amounts of some nutrient-rich products, such as meat, eggs, and dairy, for a nutritionally adequate diet. Impoverished areas that lack sufficient access to a range of affordable and nutritious food are defined as food deserts—a term that does not have a common methodology to be measured yet.

Product properties include type, quality, safety, and appeal of the products in a food environment, whereas vendor properties refer to type (e.g., chain or non-chain, corner store, or farmer's market) and location of the food outlet. For example, due to their long shelf life and higher profit margin, the share of floor space given to processed and ultra-processed foods has increased dramatically in modern food outlets.

Food advertisement has significant influence on purchasing and consumption patterns. Targeted advertisements to specific age, income, or ethnic groups are particularly troublesome as they may reinforce certain dietary patterns that result in malnutrition. For instance, children are vulnerable to advertisements for ultra-processed foods that are low in nutritional value. Moreover, large multinational companies reportedly pursue different promotion and advertisement strategies in different income settings through which higher income countries are exposed to a larger fraction of healthier food advertisements compared to lower income countries. The same may hold true for in-store food promotions offered to consumers or product placements in retail outlets with target consumers from different income settings. Finally, food labeling regulations are important in guiding and informing consumers on the nutritional content of food products and recommended/restricted intake accompanied by interventions to increase food literacy among consumers.

Food Systems and Planetary Boundaries

Food systems not only matter for human health, but they also have tremendous impacts on environmental health, together referred to as *planetary health*. Rockström introduced the concept of planetary boundaries to provide an environmental ceiling beyond which unprecedented consequences may be experienced.¹⁷ During the 11,700-year Holocene epoch, modern human societies thrived with the help of a relatively stable and warm climatic period.¹⁸ Therefore, it is assumed to be prudent to maintain these conditions for the continuity of contemporary human societies with high urbanization rates and dependence on agriculture. Planetary boundaries set limits that aim to maintain a Holocene-like state on Earth, which is assumed to represent a safe operating state (SOS).

To guide monitoring and assessments of planetary boundaries, there are nine biophysical boundaries with assigned limits¹⁹: stratospheric ozone depletion, biosphere integrity, chemical pollution, climate change, ocean acidification, freshwater consumption, land system change, biogeochemical flows, and atmospheric aerosol loading. Global food systems have been directly linked to the transgression of five of these planetary boundaries.²⁰

Figure 2: Safe and just operating space for humanity.²¹



Planetary health is a transdisciplinary framework that is used to conceptualize the links among animal, environmental, and human health.⁴⁵ It draws on knowledge from ecology, public health, economics, sociology, and evolutionary biology. As such, the planetary health approach allows us to address interconnectedness, trade-offs, and synergies in social-ecological systems, of which food systems are an example.

Climate change

Atmospheric CO₂ concentration, as measured by parts per million (ppm), and radiative forcing, watts per meter squared (Wm⁻²), are two indicators of climate change as originally suggested in the planetary boundaries framework. We can employ greenhouse gas emissions as pressure indicators of such states in the planetary boundaries.²² In this regard, 350 ppm (with an uncertainty interval of 350–450) CO₂, or an equivalent increase in top-of-atmosphere radiative forcing of +1.0 (with an uncertainty interval of 1.0 – 1.5) Wm⁻² compared to pre-industrial times, are the proposed boundaries for assessing climate change. It is worth noting here that, as of January 2021, we have long transgressed this limit and reached 415.24 ppm in the atmosphere.

Food systems are responsible for up to 30% of the global greenhouse gas (GHG) emissions from a lifecycle perspective as we include emissions from different stages of production such as transportation, processing, and packaging.²³ Nevertheless, on-farm activities represent 81% of supply chain emissions when deforestation is included and 61% of those excluding deforestation.²⁴ Of the global non-CO₂ emissions, food systems act as the largest contributor, and total emissions continue to rise despite the landmark Paris Agreement on limiting average global temperature increase to well below 2°C above preindustrial levels.²⁵ With agricultural soils, crop residues, and synthetic fertilizers, observing the largest increase over the same period (>30%), enteric fermentation from ruminants has been historically the biggest source (39%) of total agricultural

Figure 3: Total agricultural emissions (sum of enteric fermentation, manure management, rice cultivation, synthetic fertilizers, manure applied to soils, manure left on pastures, crop residues, cultivation of organic soils, burning of crop residues, and burning of savanna) in CO₂-equivalent terms for 2018. The darker the red, the higher the total emissions are.²⁶



emissions followed by manure left on pasture (16%) and manure management (6%). In return, growing concentration of GHG emissions poses substantial risks to food systems in terms of both quantity and quality through different impact pathways.

On the one hand, elevated CO₂ in the atmosphere has a fertilization effect on plant growth, which may result in higher yields while altering nutritional composition in C₃ plants (which represent the bulk of food crops including most cereals but excluding maize, soybeans, sugar beets, potatoes, and several others) such as lower protein and micronutrient density.²⁷ On the other hand, increasing CH₄ and NO_x emissions have limited fertilization effects; meanwhile, they increase ground level ozone that reduces yields.²⁸ Overall, all GHG emissions drive mean temperature increase, evapotranspiration, changes in rainfall, and consequent yield losses—the extent of which varies across temperate and tropical regions. In return, growing concentration of GHG emissions poses substantial risks to food systems in terms of both quantity and quality through different impact pathways. Beyond the farm level, climate change also poses risks further along food supply chains like during transportation or storage.²⁹ In terms of the social aspects of food systems, climate change also risks deepening inequalities in access-

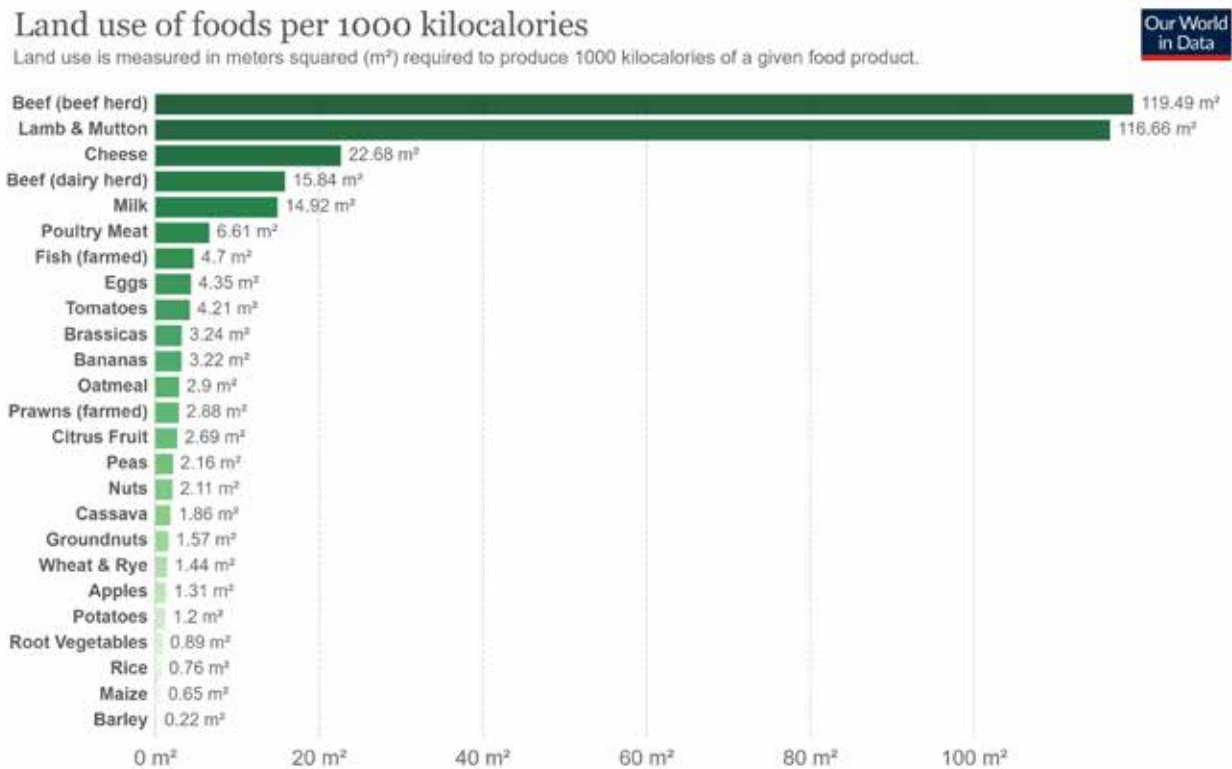
To operationalize the Sustainable Development Goals, specifically SDG 15 – Life on Land, the United Nations Strategic Plan for Forests sets a target of 3% increase in the global forest area by 2030.

ing food through widening the wealth gap and rising food prices. Increasing rates of climate change and persistent inaction only exacerbate inequality. Growing inequality and poverty, in turn, undermine the adaptive capacity and resilience of food systems. Hence, food systems and climate change are in a complex reciprocal relationship whereby any alteration of a given factor leads to additional repercussions across other dimensions of food systems.

Land system change

Human activity has long changed land cover on the planet. Land system change is focused on the biogeophysical processes that govern surface-climate interaction. Therefore, the primary indicator for the land system change boundary is the share of global forest cover remaining relative to original forest cover. The boundary is set at 75% (the uncer-

Figure 4: Global mean land area used to produce one kilogram of food products (m² per kg).³⁰



tainty interval of which is 54%–75%). Today, slightly less than 62% of the original forest cover around the world remains. In other words, we have transgressed the land system change boundary, too. At the biome level, there are three different boundaries for three major forest biomes: tropical, temperate, and boreal forests. As a result of specific feedback mechanisms, in each biome 85% (60%–85%) of the tropical forests, 85% (60%–85%) of the boreal forests, and 50% (30%–50%) of the temperate forests need to be preserved to stay within the planetary boundaries. However, in many regions with the largest forest cover around the world, we have been witnessing land conversion and destruction of forests to clear space for agricultural activities such as in South America and Africa.

Agricultural expansion has been the main driver of deforestation and forest fragmentation. Although efforts have been made to reduce deforestation via financing mechanisms (e.g., REDD+ Reducing Emissions from Deforestation and Forest Degradation and the Green Climate Fund) and the rate of deforestation decreased after 2010 (4.74 million ha/year lost) compared to the 1990s (7.84 million

ha/year lost), more action is needed, particularly in developing countries in which population growth and the need for increasing food production adds continuing pressure. The primary agricultural activities that put major pressure on forests are large-scale cattle ranching and oil palm and soybean cultivation. These three activities have caused more than 40% of deforestation in tropical biome between 2000 and 2010.

Freshwater consumption

The global water cycle is a complex Earth system process. Water provides life for all living beings. The planetary boundary for water is set for global consumptive blue water use at the rate of 4,000 km³/year (with an uncertainty interval of 4,000–6,000 km³/year). As of 2009, an estimated 2,600 km³/year of blue water is consumed by humans worldwide. However, similar to land system change, freshwater consumption has varying limits for different types and scales. Hydrological responses to the stressors on freshwater availability vary by water basin at different scales. Hence, there is growing criticism of setting a single global

Green water: Water from precipitation that has transpired from plants and is stored in soil.

Blue water: Water in lakes, rivers, reservoirs, and groundwater reservoirs.

Gray water: Domestic wastewater generated in households or commercial buildings, excluding streams from toilets that are contaminated with feces.

indicator for this freshwater boundary rather than regional/local boundaries that would account for local conditions, although the very nature of the planetary boundaries framework is to set limits on a planetary scale.³¹

Globally, agricultural activities consume around 72% of all water withdrawals, while 16% is used by municipalities and 12% is used by industrial activities.³² The role of agriculture in freshwater use is highest in Africa (~87%) and Asia (~80%).³³ In terms of consumptive water use, referring to the amount of water that is not reused downstream, more than 90% is claimed by the agriculture sector.³⁴ As water resources become depleted by human consumptive uses and changes in precipitation regimes due to climate change, sustainable water management has gained increasing attention on the political agenda. As of 2017, 24% of global total cropland (arable land + land used for permanent crops) is equipped for irrigation, and around 85% of this equipped cropland is actually irrigated. Consequently, rain-fed agriculture represents around 60% of global crop production by quantity, the majority of which is used to grow cereals. Irrigated land is expected to increase by ~12% by 2050 compared to the 2005/2007 reference period.³⁵

Climate change-driven alterations in precipitation regimes and temperatures exacerbate water and heat stress in agricultural production. Although the extent of water stress is more pronounced in rain-fed croplands, mitigation through irrigation is also limited under heat stress and/or other constraints such as soil nutrients. Moreover, agricultural water use efficiency, defined as the amount of biomass

produced via carbon assimilation per unit of water used by a plant, represents a trade-off between transpiration and photosynthesis. Increased atmospheric CO₂ concentration may result in greater water use efficiency in some plants, while consequent heat stress would counteract this due to lower yields and crop failures. The overall net impact varies by region depending on environmental and climatic conditions as well as production systems, but the need for increased water use efficiency remains crucial to stay within the safe operating space (SOS).³⁶

Biogeochemical flows

Biogeochemical cycles refer to the fluxes of chemical substances among biotic and abiotic parts of the Earth. Of interest for Earth-system stability and resilience, planetary boundaries are defined for phosphorus and nitrogen flows to the biosphere and oceans. It is, however, important to note that there is growing support for defining boundaries for other elements such as silicon that are central to Earth-system functioning.³⁷ Much of the phosphorus and nitrogen introduced to agricultural landscapes end up in aquatic systems and cause eutrophication. Excessive nitrogen also accumulates in the soil and increases the concentration of N₂O (a potent greenhouse gas) and reactive nitrogen in the troposphere.

The limit for global phosphorus flows from freshwater systems into the oceans to prevent large-scale anoxic events is set at 11 TgP/year (with an uncertainty interval of 11-100 TgP/year). Additionally, a regional phosphorus boundary for phosphorus flows from fertilizers (mined phosphorus) to erodible soils is set at 6.2 TgP/year (6.2-11.2 TgP/year). The nitrogen boundary, on the other hand, is set for industrial and intentional biological fixation of nitrogen to be limited to 62 TgN/year (62-82 TgN/year) at the global scale. In doing so, unintended NO_x emissions from industrial activities are not taken into account as these emissions lead to NO_x-induced elevated ozone concentrations rather than agricultural nitrogen fixation and consequent runoff.

Currently, we have transgressed the boundaries for both nitrogen and phosphorus cycles with circa 22 TgP/year globally and 14 TgP/year regionally in

addition to more than 150 TgN/year globally. Such high volumes of interference with the phosphorus and nitrogen cycles have had devastating ecological consequences such as the oxygen-deprived dead zones in the Gulf of Mexico, which has been linked to agricultural activities in the Midwestern United States, Lake Winnipeg in Canada, and the Baltic Sea. Furthermore, nutrient cycles are strongly coupled with carbon cycles through interference with photosynthesis, decomposition, and microbial activity, which would have a decisive impact on atmospheric CO₂ trajectories.³⁸

Phosphorus and nitrogen cycles have been primarily altered by agricultural activities, specifically through fertilizer production and application. Both substances are essential primary macronutrients for plant growth and nutrition. However, excess consumption of these macronutrients often leaches into the soil and freshwater ecosystems. More than 85% of nitrogen and more than 95% of mined phosphorus is used in fertilizer production. Globally, nitrogen application from fertilizers has increased by more than seven-fold, and consumption of phosphate fertilizer has almost tripled since the early 1960s. The growth in consumption has been uneven such that many developed regions like North America and Europe have over-applied fertilizers, although the volume in Europe has leveled off since the early 1990s. In contrast, many low-income countries in Sub-Saharan Africa and some parts of Southeast Asia still have large yield gaps to attain maximum attainable yield, partly due to low soil nutrient levels. Furthermore, research shows low phosphorus- and nitrogen-use efficiency values, which have resulted in high losses. Finally, around half of global fertilizer consumption is used to grow cereals³⁹ one-third of which is fed to livestock.⁴⁰

Biosphere integrity

Biodiversity is vital for provisioning (e.g., food, energy, and timber) and regulating (e.g., climate, biocontrol, pollination, soil, and water) ecosystem services. Anthropogenic drivers of ecosystem change have been more rapid since the onset of the Industrial Revolution. These drivers primarily include growing demand for food, water, and timber. It is fundamentally impossible to identify to what extent we can afford biodiversity loss; hence,

there cannot be a single planetary boundary for biosphere integrity at the global or continental scale. Current control variables are merely interim controls, and there is growing research to develop more appropriate ones. Nevertheless, two key roles of the Earth's biosphere can be examined through setting both genetic and functional diversity as the control variables. Genetic diversity is gauged by extinction rate (extinction rate per million species-years, E/MSY) with an *aspirational* goal of 1 E/MSY and an uncertainty bound to 10 E/MSY. Functional diversity is measured by the biodiversity intactness index, which represents the average abundance of a wide set of taxa in a particular biome compared to the pre-industrial reference levels. In this regard, 100% translates to an intact ecosystem that is as abundant across all functional groups as pre-industrial levels. The proposed boundary is to maintain a biodiversity intactness index at 90% or above (with an uncertainty range of 30%–90%). It is estimated from the fossil records that human-driven species extinctions are 100 to 1,000-fold the background rates of 0.1 – 1 in the pre-industrial era, while the average global biodiversity intactness index is recently estimated as approximately 85%, although this is a coarse and potentially optimistic estimate due to data gaps present in this field.⁴¹

Food systems play a substantial role in the alteration of biosphere integrity. There are different pathways through which food systems activities impose increasing pressure on biodiversity. There are direct threats to biosphere integrity such as overexploitation of life on land or under water through fishing (one-third of global fish stocks are overfished), hunting, harvesting, and/or gathering to provide food for humans. Human-induced alterations to the environment also lead to indirect impacts. Food systems activities may create inadequate conditions for a great number of species. For instance, fertilizer runoff and accumulation often result in eutrophication, soil acidification, and eco-toxicity, which in turn affect the organisms in those environments. Moreover, land use and land use changes for food production are likely to cause habitat fragmentation, reduction, and destruction.⁴² Although food production is estimated to be responsible for up to 80% of the change in biosphere integrity,⁴³ different types of food sources and production practices have different contributions. Consequently, the biodiversity footprint of human nutrition

differs greatly by the source. For example, annual crops have a larger biodiversity footprint than perennials due to the former requiring, e.g., more frequent land disturbance.⁴⁴ Additionally, due to agro-ecological conditions, some crops are very limited in global distribution, and this can exacerbate the local/regional pressures induced by global consumption. Coffee and sugarcane are among such products, for where they are grown (i.e., in the tropics) has high species richness and high proportion of endemic species. Overall, as much as they have different nutritional profiles, different food sources also have different impacts on biodiversity.

Conclusion

Food systems are complex and diverse social-ecological systems that involve biophysical (e.g., climate and soil), social (e.g., cultural norms, entitlements, and socioeconomic factors), and political (e.g., policies and incentives) factors. Their analysis requires an interdisciplinary approach, including but not limited to nutritionists, environmental and climate scientists, economists, political scientists, and agricultural scientists, to attain food and nutrition security sustainably. Although the type of food system may differ at the local level, most are connected at the global level.

Poor diets play a primary role in the global burden of disease. Different forms of malnutrition affect more than 3 billion people worldwide. The burden of malnutrition costs the global economy 3.5 trillion USD per year. Maternal and child malnutrition is responsible for more than 10% of the global burden of disease, while 2.6 million people each year die from complications related to being overweight or obese. Research also suggests that the burden of malnutrition shifts to the poor in low- and middle-income countries.

The environmental impacts of food systems differ by production system, production basket, and local agro-ecological conditions. The planetary boundaries framework sets limits that aim to maintain a Holocene-like state on Earth that represents a safe operating state (SOS) for nine Earth-system processes. In the context of food systems, climate change, land system change, freshwater consump-

tion, biogeochemical flows, and biosphere integrity are of primary importance. While food systems account for up to 30% of global greenhouse gas emissions, climate change also poses substantial threats to the quantity and quality of food production. Agricultural area expansion is the main driver of deforestation, with devastating effects on other planetary boundaries. Moreover, while agriculture accounts for more than 90% of consumptive water use, climate change threatens water availability in many major producing regions. Fertilizer runoff from agricultural landscapes has already caused transgression of planetary boundaries for phosphorus and nitrogen cycles, leading to adverse impacts in freshwater and terrestrial ecosystems. Finally, although hard to provide robust estimations on biosphere integrity due to limited data, up to 80% of the change in biosphere integrity is attributed to agricultural activities as they drive the primary threats to biodiversity.

Overall, as diets determine planetary health—illustrating the interdependent relationship between humans and environmental health—a diverse and coherent set of policies that takes into account all aspects of food systems is urgently needed to nourish a growing population within a safe operating space.

Endnotes

- 1 | United Nations, “Annex: Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development,” Work of the Statistical Commission pertaining to the 2030 Agenda for Sustainable Development, 2017, https://unstats.un.org/sdgs/indicators/GlobalIndicatorFramework_A.RES.71.313Annex.pdf, 1–21.
- 2 | B.M. Popkin, “Global nutrition dynamics: the world is shifting rapidly toward a diet linked with noncommunicable diseases,” *The American Journal of Clinical Nutrition* 84, no. 2 (2006): 289–298, doi: 10.1093/ajcn/84.2.289.
- 3 | B. Caballero and B.M. Popkin, “1 - Introduction,” in *The Nutrition Transition*, ed. B. Caballero and B.M. Popkin, 1–6 (London: Academic Press (Food Science and Technology), 2002), doi: <https://doi.org/10.1016/B978-012153654-1/50003-9>; B.M. Popkin and P. Gordon-Larsen, “The nutrition transition: Worldwide obesity dynamics and their determinants,” *International Journal of Obesity* 28 (2004): S2–S9, doi: 10.1038/sj.ijo.0802804; C. Hawkes, “The WHO commission on social determinants of health: Globalization, Food and Nutrition Transitions, Globalization Knowledge Network,” Institute of Population Health, University of Ottawa, 2007.
- 4 | Hawkes, “The WHO commission on social determinants.”
- 5 | S. Kalemli-Ozcan, “Does the mortality decline promote economic growth?” *Journal of Economic Growth* 7, no. 4 (2002): 411–439, doi: 10.1023/A:1020831902045.
- 6 | A.R. Omran, “The Epidemiological Transition: A theory of the epidemiology of population change,” *Milbank Mem Fund Q* 49, no. 4 (1971): 509–538.
- 7 | R. Kyte et al., “Healthy diets for all: A key to meeting the SDGs,” Global Panel, SDG Policy Brief No. 10, 2017, <http://glopan.org/sites/default/files/Downloads/SDGPolicyBrief.pdf>, 20.
- 8 | FAOSTAT, “Suite of Food Security Indicators. Prevalence of undernourishment,” 2020, accessed February 2, 2020, <http://www.fao.org/faostat/en/#data/FS>.
- 9 | P. Webb et al., “The urgency of food system transformation is now irrefutable,” *Nature Food* 1 (2020): 584–585, doi: 10.1038/s43016-020-00161-0.
- 10 | Popkin and Gordon-Larsen, “The nutrition transition.”
- 11 | J. Ingram, “A food systems approach to researching food security and its interactions with global environmental change,” *Food Security* 3, no. 4 (2011): 417–431. doi: 10.1007/s12571-011-0149-9.
- 12 | HLPE, “Nutrition and food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security,” 2017.
- 13 | Development Initiatives, “2020 Global Nutrition Report: Action on equity and malnutrition,” Bristol, UK, 2020.
- 14 | O. Geyik, M. Hadjikakou, and B.A. Bryan, “Spatiotemporal trends in adequacy of dietary nutrient production and food sources,” *Global Food Security* 24 (March 2020): 100355, doi: 10.1016/j.gfs.2020.100355.
- 15 | O. Geyik et al., “Does global food trade close the dietary nutrient gap for the world’s poorest nations?” *Global Food Security* 28 (2021): 100490, doi: <https://doi.org/10.1016/j.gfs.2021.100490>.
- 16 | D.D. Headey and H.H. Alderman, “The Relative Caloric Prices of Healthy and Unhealthy Foods Differ Systematically across Income Levels and Continents,” *Journal of Nutrition* 149, no. 11 (2019): 2020–2033, doi: 10.1093/jn/nxz158.
- 17 | J. Rockström et al., “A safe operation space for humanity,” *Nature* 461 (September 2009): 472–475.
- 18 | K. Meyer and P. Newman, “The Holocene, the Anthropocene, and the Planetary Boundaries BT,” in *Planetary Accounting: Quantifying How to Live Within Planetary Limits at Different Scales of Human Activity*, ed. K.

- Meyer and P. Newman, 35–52 (Singapore: Springer, 2020), doi:10.1007/978-981-15-1443-2_3.
- 19 | Rockström et al., “A safe operation space for humanity”; W. Steffen et al., “Planetary boundaries: Guiding human development on a changing planet,” *Science* 347 (2015): 6223, doi: 10.1126/science.1259855.
- 20 | Steffen et al., “Planetary boundaries: Guiding human”; B.M. Campbell et al., “Agriculture production as a major driver of the Earth system exceeding planetary boundaries,” *Ecology and Society* 22, no. 4 (2017): Art 8, doi: 10.5751/ES-09595-220408; W. Willett et al., “Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems,” *The Lancet* 393, no. 10170 (2019): 447–492, doi: 10.1016/S0140-6736(18)31788-4.
- 21 | Kate Raworth, “A Safe and Just Space for Humanity: Can We Live within the Doughnut?” Oxford, 2012, https://www-cdn.oxfam.org/s3fs-public/file_attachments/dp-a-safe-and-just-space-for-humanity-130212-en_5.pdf.
- 22 | Steffen et al., “Planetary boundaries: Guiding human.”
- 23 | J. Poore and T. Nemecek, “Reducing food’s environmental impacts through producers and consumers,” *Science* 360, no. 6392 (2018): 987–992, doi: 10.1126/science.aaq0216; S.J. Vermeulen, B.M. Campbell, and J.S. Ingram, “Climate Change and Food Systems,” *Annual Review of Environment and Resources* 37, no. 1 (October 17, 2012): 195–222, <https://doi.org/10.1146/annurev-environ-020411-130608>.
- 24 | Poore and Nemecek, “Reducing food’s environmental impacts.”
- 25 | FAOSTAT, “Emissions - Agriculture. Agriculture Total,” 2019, <http://www.fao.org/faostat/en/#data/GT/visualize>.
- 26 | “Food Systems Dashboard,” 2019, <https://foodsystemsdashboard.org/>.
- 27 | L.H. Dietterich et al. “Impacts of Elevated Atmospheric CO₂ on Nutrient Content of Important Food Crops,” *Scientific Data* 2 (2015): 1–8, <https://doi.org/10.1038/sdata.2015.36>; M.R. Smith and S.S. Myers, “Impact of Anthropogenic CO₂ Emissions on Global Human Nutrition,” *Nature Climate Change* 8, no. 9 (September 27, 2018): 834–39, <https://doi.org/10.1038/s41558-018-0253-3>; C. Zhu et al., “Carbon Dioxide (CO₂) Levels This Century Will Alter the Protein, Micronutrients, and Vitamin Content of Rice Grains with Potential Health Consequences for the Poorest Rice-Dependent Countries,” *Science Advances* 4, no. 5 (May 23, 2018): eaaq1012, <https://doi.org/10.1126/sciadv.aaq1012>.
- 28 | D.T. Shindell, “Crop yield changes induced by emissions of individual climate-altering pollutants,” *Earth’s Future* 4 (2016): 373–380; D. Shindell, G. Faluvegi, P. Kasibhatla, and R. Van Dingenen, “Spatial Patterns of Crop Yield Change by Emitted Pollutant,” *Earth’s Future* 7 (2019): 101–112.
- 29 | J. Fanzo, R. McLaren, C. Davis, and J. Choufani, “Climate change and variability what are the risks for nutrition, diets, and food systems?” *IFPRI - Discussion Papers* vi-pp (2017).
- 30 | Poore and Nemecek, “Reducing food’s environmental impacts.”
- 31 | J. Bunsen, M. Berger, and M. Finkbeiner, “Planetary boundaries for water – A review,” *Ecological Indicators* 121 (September 2020): 107022, doi: 10.1016/j.ecolind.2020.107022.
- 32 | UN Water, “Summary Progress Update 2021 : SDG 6 — water and sanitation for all,” Geneva, Switzerland, 2021.
- 33 | Campbell et al., “Agriculture production as a major driver.”
- 34 | I.A. Shiklomanov and J.C. Rodda, ed., *World water resources at the beginning of the twenty-first century* (Cambridge: Cambridge University Press, 2003), doi: 10.5860/choice.41-4063.
- 35 | N. Alexandratos and J. Bruinsma, “WORLD AGRICULTURE TOWARDS 2030 / 2050: The 2012 Revision,” *Food and Agriculture Organization of the United Nations* 12 (2012): 146, doi: 10.1016/S0264-8377(03)00047-4.

- 36 | Z.W. Kundzewicz et al., “Freshwater resources and their management,” in *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. M.L. Parry et al., 173–210 (Cambridge, UK: Cambridge University Press, 2007); B.E. Jiménez Cisneros et al., “Freshwater resources,” *Climate Change 2014 Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects* (2015): 229–270, doi: 10.1017/CBO9781107415379.008.
- 37 | Steffen et al., “Planetary boundaries: Guiding human.”
- 38 | P.E. Thornton et al., “Influence of carbon-nitrogen cycle coupling on land model response to CO₂ fertilization and climate variability,” *Global Biogeochemical Cycles* 21, no. 4 (2007), doi: <https://doi.org/10.1029/2006GB002868>.
- 39 | International Fertilizer Association, “Global Sustainability Report 2019,” 2020.
- 40 | FAOSTAT, “Food Balance Sheets,” 2017, accessed August 3, 2019, <http://www.fao.org/faostat/en/#data/FBS>.
- 41 | Steffen et al., “Planetary boundaries: Guiding human”; T. Newbold et al., “Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment,” *Science* 353, no. 6296 (2016): 288–291, doi: 10.1126/science.aaf2201.
- 42 | IUCN, “IUCN - CMP Unified Classification of Direct Threats,” 2012, <https://www.iucnredlist.org/resources/threat-classification-scheme>.
- 43 | Campbell et al., “Agriculture production as a major driver.”
- 44 | A. Chaudhary and T. Kastner, “Land use biodiversity impacts embodied in international food trade,” *Global Environmental Change* 38 (2016): 195–204, doi: 10.1016/j.gloenvcha.2016.03.013.
- 45 | A. Foster, J. Cole, A. Farlow, and I. Petrikova, “Planetary Health Ethics: Beyond First Principles,” *Challenges* 10, no. 14 (2019).

Özge Geyik is a 2020/21 Mercator-IPC Fellow at IPC and PhD candidate at the School of Life and Environmental Sciences, Deakin University, Australia, focusing on sustainable and nutrition-sensitive food systems.

Sustainable and Nutrition-Sensitive Food Systems: The Planetary Boundaries Approach

16 p.; 30 cm. - (Istanbul Policy Center-Sabancı University-Stiftung Mercator Initiative)

ISBN 978-625-7329-26-2

Cover Design and Page Layout: MYRA

Istanbul Politikalar Merkezi

Bankalar Caddesi Minerva Han No: 2 Kat: 4

34420 Karaköy-İstanbul

T +90 212 292 49 39

ipc@sabanciuniv.edu - ipc.sabanciuniv.edu

IPC

ISTANBUL POLICY CENTER

SABANCI UNIVERSITY

STIFTUNG MERCATOR INITIATIVE