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CHAPTER 3

ECO-AGRI-FOOD SYSTEMS: TODAY'S REALITIES AND TOMORROW'S CHALLENGES

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SUMMARY

Chapter 3 provides an overview of the diversity of agriculture and food systems, each with different contributions to global food security, impacts on the natural resource base and ways of working through food system supply chains. We describe "eco-agri-food systems" and further identify their many manifestations through a review of typologies. We identify challenges ahead with existing systems due to prevailing economic and political pressures resulting in patterns of invisible flows and impacts across global food systems. We describe pathways to ensure sustainability by securing the benefits from working with, rather than against, natural systems and ecosystem processes and the challenges for farmers, communities and societies to reorient food value chains and build resilience in eco-agri-food systems.

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CHAPTER 3

3.0 KEY MESSAGES

- This chapter provides an overview of the complexities, roles and functions of eco-agri-food systems. The diversity of global agriculture and food production systems is profiled; the challenges ahead for the world's agriculture and food systems are presented; and pathways to sustainability for agriculture and food systems, building on ecosystem services and biodiversity, are explored.
- Globally, there many diverse types of agriculture and food systems, each with different contributions to global food security, impacts on natural resources and varying ways of working through food system supply chains. Using a typology recently adopted by international initiatives, the world's food systems can be characterized as traditional, mixed and modern. Each of these systems can strengthen their linkages to natural capital and ecosystem service provisioning.
- The contribution of small and medium sized farms of traditional and mixed systems – providing food to an estimated two thirds of the world's population in highly diverse landscapes – is highlighted, reinforcing the contribution of ecosystem services and biodiversity in food and agriculture.
- Prevailing economic logic reinforces forms of food production that fail to account for the contributions of nature, while negatively impacting both the environment and human welfare. This situation has created externalities such as wide¬spread degradation of land, water and ecosystems; high greenhouse gas emissions; biodiversity losses; chronic over- and undernutrition and diet-related diseases; and livelihood stresses for farmers around the world. The nature of international trade resulting from such forces and pressures has many ramifications for equity and sustainability.
- An emerging feature of global food systems is the existence of multiple, insidious forms of visible and invisible flows of natural resources. Socio-economic crises and the often-unpredictable impacts of climate change present additional and compounding challenges for farmers and local communities.
- Pathways to sustainability, going forward, must recognize and strengthen those forms of agricultural production that explicitly enhance biodiversity and ecosystem services and build the natural capital that underpins food systems, creating regenerative forms of agriculture and food systems that generate positive externalities.
- Pathways to sustainable food systems must look at the dependencies and interactions within the entire food chain and at multiple scales, from farm to landscape to city to regional food systems.

CHAPTER 3

ECO-AGRI-FOOD SYSTEMS: TODAY'S REALITIES AND TOMORROW'S CHALLENGES

3.1 INTRODUCTION TO AN 'ECO-AGRI-FOOD' SYSTEM APPROACH

Food—the ultimate source of energy and nutrients—is the central reason for agricultural production around the world (TEEB 2015) and sustains human life (Vivero-Pol 2017). The increasing complexity of the global food system and its intricate linkages with other systems related to energy, health, soils, water, human knowledge, ecosystems, etc. are changing how food systems function. To grasp this complexity and deepen the understanding of the role and function of food systems, TEEB for Agriculture & Food (TEEBAgriFood) is presenting a broadly encompassing perspective that goes beyond the production, processing, transport and consumption of food. As defined by TEEB, an 'eco-agri-food' system refers to the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labour, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food.

This chapter explores the underpinnings of the 'eco-agri-food system', first by reviewing the predominant trends and patterns in the ways that agriculture and food goods are being produced globally. As human populations have grown over time, agriculture and food production systems have experienced dramatic changes, increasing the levels of production well beyond what could have been imagined a hundred years ago. Yet as these systems have become increasingly productive and global in nature, significant challenges are impacting upon them. Global issues related to food security and sovereignty, nutrition and health, climate change, migration and economic crises show that current food systems are not functioning adequately and are in dire need of reconfiguration. Since the 1950s, with the growing demand for agricultural produce, many farmers began using non-renewable energy-based chemical fertilizers and agricultural processes became specialized and more monocultural. Ways of processing and distributing food have emphasized low cost and high productivity while often devaluing the freshness or wholesomeness of food. We must be reminded that agriculture and food production are fundamentally biological processes, reliant on biodiversity and ecosystem functions and processes. Agriculture imposes a heavy toll on the environment when it tries to escape its essential biological limits, yet at the same time these ecological functions are key to the sustainability and regenerative potential of farming and food systems. Many multinational, national and local organizations and initiatives are attempting to change the existing pattern so that proper balance with environment is created and any conflict (economic, political, social) is minimized. TEEB is one of these efforts, in particular seeking to develop the tools to value ecological functions that contribute to our food system, and the negative and positive externalities that emanate from managing theses agricultural and food systems. TEEBAgriFood aims to offer an integrated and holistic perspective that brings such issues into focus.

In this chapter, we unpack the eco-agri-food system, and identify its many manifestations through a review of typologies (Section 3.2). We then identify the challenges ahead (Section 3.3) and finish with a section (Section 3.4) describing pathways to improve the status of agricultural and food systems by securing the benefits derived from working with, rather than against, natural systems and ecosystem processes.

3.2 TYPOLOGIES OF ECO-AGRI-FOOD SYSTEMS

3.2.1 Definition of eco-agri-food systems

In Chapter 1, the eco-agri-food system was introduced. In Chapter 2, generic features of eco-agri-food systems were described, and the importance of understanding multiple interactions and dynamics through systems thinking was highlighted. In this chapter, we aim to unpack those generic features, and characterise the diversity and salient aspects of the main food systems found around the globe that are of relevance to a TEEBAgriFood analysis.

3.2.2 Characterizing the diversity of eco-agri-food systems

At a broad spatial scale, one may define an agricultural system as the land area in a region, district, or landscape that produces a particular commodity or various crops (Jones *et al.* 2016). TEEB (2015) defines 'agricultural system' as an assemblage of components which are united by some form of interaction and interdependence and which operate within a prescribed boundary to achieve a specified agricultural objective on behalf of the beneficiaries of the system". For our purposes, we are focusing on agricultural systems with respect to the integration of their different components such as natural resources, energy, labour, marketing, finances, genetic stock, nutrition, equipment, and hazards—thus the broader food system. This has been defined as the interdependent sets of enterprises, institutions, activities and relationships that collectively develop and deliver material inputs to the farming sector, produce primary commodities, and subsequently handle, process, transport, market and distribute food and other agro-based products to consumers (UNEP 2016). It thus includes production, harvesting, storage, processing, packaging, marketing, trade, transport, demand, preparation, consumption and food disposal. It thus includes production, harvesting, storage, processing, packaging, marketing, trade, transport, demand, preparation, consumption and food disposal. As a system, it extends to inputs needed and outputs generated at each step as well as governance, research, education and varied (e.g. financial) services around food provisioning.

Food (value) chains are one of the core elements of a food system that feed a population. Clearly, value chains are created around economic value and respond to supply and demand. However, they can also impact and be impacted by issues related to the environment, nutrition, equity, quality, cultural acceptability of food. Food systems also include political, economic, socio-cultural and environmental drivers and outcomes that affect actors and stakeholders. Thus, the definition of food systems should include activities (from production to consumption), outcomes of the activities (food security, ecosystem services, biodiversity, social welfare), and interactions between and within biogeophysical and human environments (Ericksen 2008). The interactions among these components may become more important than how each component functions independently.

Diversity in agriculture is the result of the co-evolution, in time and space, of human societies and ecosystems, through the practice of farming, unfolding in different patterns of resource use and development trajectories (Ploeg and Ventura 2014). The heterogeneity of farming systems reflects the diversity of social, economic and ecological responses to changing adaptive conditions in different settings (Ploeg 2010).

Certainly, there are unlimited permutations of the components of eco-agri-food systems, and a great number of ways of characterizing these. Often contrasting systems are described as dichotomous entities, from traditional peasant systems to "modern" food systems, or as those characteristic of developed versus developing countries. From the TEEBAgriFood perspective, there are many different types of agriculture and food systems, each with different contributions to global food security and different impacts on the natural resource base. If we are to better understand the possible pathways towards sustainable food systems and to encourage intervention from different stakeholders around the world, we need a workable way of characterizing this diversity.

Within a TEEBAgriFood perspective, we suggest it is most productive to adopt current typologies as developed by ongoing international processes, and to take these as a starting point to further describe the pathways that diverse systems may take to recognize externalities and reorient toward more sustainable solutions. A useful typology is that developed by the International Resource Panel of the United Nations Environment (UNEP 2016) and the related High-Level Panel of Experts on Food Security and Nutrition's report on Nutrition and Food Systems (HLPE 2017).

The International Resources Panel recognizes the diversity of food systems across the world, and their multifarious interactions: nonetheless, distinguishing between traditional food systems, mixed food systems, and modern food systems can be helpful. Salient characteristics of these, relevant for the TEEBAgriFood Evaluation Framework, are described below (UNEP 2016; HLPE 2017).

Before presenting the aligned typologies of the HLPE and UNEP, we should note that the Global Nutrition Report (IFPRI 2015) has developed a food system classification on a country level that considers differences between industrial, mixed, transitioning, emerging and rural food systems; this typology maps to the three classifications mentioned above (and by the International Resource Panel and the HLPE Report), but with a finer level of distinction and disaggregation to national levels.

The three classifications – traditional food systems, modern food systems, and mixed food systems - are described in detail in **Table 3.1** and the sections below (while noting that these are not distinct categories, but rather a way of classifying a complex continuum):

Traditional food systems: These may also be considered low-external input-intensive food systems, which primarily make use of naturally generated inputs, human knowledge and skills, and production practices that have been maintained by communities over generations. Yields and productivity tend to be low in comparison to high-input systems, although societies within traditional food systems generally value benefits well beyond production and income. Under often challenging biophysical conditions, traditional food systems have often developed ways of sustaining agricultural production in places where modern, mechanized agriculture would not succeed. Agricultural products are either self-produced or sold in local markets and are largely unprocessed, or are processed by the local consumers. Production, trade and processing takes place in small-scale operational units. Linkages with larger commercial operations are scarce. Consumption patterns correspond to seasonal harvests, and are usually dominated by plant-based products, (although a considerable component of traditional communities such as pastoralists, fisherfolk, and forest dwellers may specialize in livestock, fish or wild meat and honey, respectively). Access to perishable foods such as certain fruits and vegetables and animal source foods depends on proximity to the source; thus, local markets are highly important for food security and nutrition. As food security primarily depends upon local sources, pressures on these sources such as extreme weather events or population changes demand new, usually local responses.

Examples of traditional food systems include Andean agricultural systems where farming communities cultivate more than 1,000 native varieties of potatoes adapted to different environments ascending the Andes under terrace management. The Ifugao rice terraces in the Philippines have retained their viability and efficacy over 2000 years in a system intimately intertwined with that of the local communities' culture and beliefs, religious rituals and traditional environmental management and agricultural practices (Koohafkan and Altieri 2011).

Traditional food systems often include an important livestock component, such as pastoralism. The Maasai in Kenya and Tanzania, for example, practice a pastoral system, in its essential elements, that is over 1000 years old. To this day, it strikes a social and environmental balance in a fragile environment, sustaining livestock production and conserving critical habitat for wildlife (Koohafkan and Altieri 2011). In Europe, the transhumant pastoralists in Eastern Spain, or the Sami people in the artic are among hundreds of good examples of communities employing traditional food systems.

Small-scale fisheries are another important production system for subsistence or local markets, often using traditional fishing techniques and small boats. Collectively, small-scale fisheries catch a large proportion of all fish caught for human consumption, and employ 90% of the labour involved in capture fisheries (FAO 2016b).

Traditional systems tend to have low use of external inputs and focus on stability rather than increase in production. Communities practicing traditional systems sustain themselves by engaging in cultural activities that, tied to the traditions of certain communities and inherited forms of production, replicate and improve their own production and consumption systems, incorporating cultural and religious elements, as well as social practices, for the management of resources.

Modern food systems: These are systems that are generally characterized as high external-input, high productivity systems, with a strong dependence on purchased or external inputs such as modern crop seeds, fertilizers, pesticides and fuel-based mechanical inputs. There is a strong economic incentive to avoid risks of crop loss by over-applying both pest control and fertilizers, resulting in on-site pollution, run-off and contamination of adjacent land and water. The impacts of intensive agricultural systems on soil health, freshwater quantity and quality, greenhouse gas emissions, and the capacity to conserve biodiversity and generate ecosystem services may be strongly negative (Pingali 2012; Godfray *et al.* 2010).

While farming systems may be considered "modern", farmers around the world are generally operating at small margins, sometimes compensated by government subsidies. Capacities to invest in more regenerative practices are thus limited. Crops and livestock rearing systems, often closely connected in traditional systems, are generally separated in modern food systems. The processing, distribution and retail sides of the food chain in modern food systems are usually specialized and elaborate, and provide substantial employment and value addition, but are also greenhouse gas-intensive. The modern food system is characterized by specialized input producers and agricultural companies, operating at large and often transnational scale. The production focus now includes not only food for direct human consumption, but also biofuels and animal feed. The processing and retail segments of modern food systems have a major influence on both production systems and consumer behaviour. Consumers in modern food systems have the choice to purchase food from sources all over the world, much of it in a processed form. However, "food deserts[1]" and "food swamps[2]" may be common in low-

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[1] Described as geographic areas where residents' access to food is restricted or non-existent due to the absence or low density of "food entry points" within a practical travelling distance (HLPE 2017)

[2] Described as geographic areas where there is an overabundance of "unhealthy" foods but little access to "healthy" foods. (HLPE 2017)

income areas, creating areas of food insecurity within modern food systems. Consumption of meat, trans fats and sugary foods is much higher in modern systems than in other food systems. The cost of staples, such as rice and wheat flour, is lower than animal-sourced foods and perishable fruits and vegetables. Consumers have access to fairly complete information on food labels, and dietary guidance is widely disseminated, though not necessarily widely used. Modern food systems are associated with comparatively lower levels of undernutrition (although concentrated areas do occur), but higher levels of overweight and obesity (Ng *et al.* 2014).

More recent trends in modern food systems include greater reliance on modern biotechnology such as genetic modification, molecular markers, hydroponics and precision-farming tools (e.g. GPS, GIS, satellite images, automatic mapping) and procedures that increase the application efficiency of inputs (Pingali 2012). For example, in places with land or weather constraints, experimentation with hydroponics is underway. In Japan, rice is harvested in underground vaults without the use of soil. Israel also, where the management of water is a key point, is experimenting with these new tools and innovations. In USA, hydroponics farming revenues reached $821 million nationwide in 2016, growing at a rate of four to five per cent since 2011, with 2,347 hydroponic farms (Ali 2017).

A parallel trend within modern food systems is a return to more organic, local/small-scale and diversified practices, from production to retail sales. Major aspects of this trend can be captured under the umbrella of agroecology, in its different aspects as a science, a practice and a movement (Wezel *et al.* 2009). As a science, agroecology reorients agronomic science to build on the ecological foundations of farming and agriculture, combining different elements of nature and its services to maximize synergies between them. As a practice, agroecology is not prescriptive; it is based on applying a set of principles (for example, "enhance recycling of biomass, optimizing nutrient availability and balancing nutrient flow") to local contexts (TWN-SOCLA 2015). As a social movement, the focus of agroecology has moved from the field and farm scale to the entire food system, emphasizing the importance of building food networks that link all parts of the food system, and advocating for social equity and food system transformation (Gliessman 2015). The farming traditions that reflect the application of agroecological principles in one form or another include: 'permaculture' associated with the ecologist Bill Mollison, 'biodynamic farming' following the principles of the anthroposophist Rudolf Steiner, the 'one-straw revolution' founded by the Japanese farmer Masanobu Fukuoka, the 'Biointensive' farming system popularized in the U.S. by John Jevons, the 'No Tillage' movement in Brazil led by Ana Primavesi, 'Agroecology' as described by Miguel Altieri and Stephen Gliessman in the U.S., Latin America, Africa and Asia, and the wide range of farming systems that in one way or another subscribe to the formal definition of 'organic farming' institutionalized by the International Federation of Organic Agriculture Movements (IFOAM). These food systems are often meant for international markets, but also used for home consumption, solidarity markets and other approaches to land and food sovereignty such as promoted by La Via Campesina, the international movement of Agrarian Federations for Farmers in the world.

Mixed food systems: While most 'modern' food systems may be found in Europe, the U.S. and other industrialized countries, and 'traditional' food systems are far more common in less industrialized regions, a vast range of intermediate, or 'mixed', food systems exist throughout the globe, supplying food to an estimated four million people. Particularly in Latin America, Asia, Eastern Europe and in some African countries, small and medium-sized farms provide the majority of food to local and national populations. In mixed systems, farmers integrate or incorporate some elements of different technological packages; for example, they may use pesticides and fertilizers, but plant farmer-saved, traditional varieties. Food producers rely on both formal and informal markets to sell produce. The food systems, however, are not uniformly small scale; the processing and retail segments of the system are often quite commercialized and in the process of becoming linked into regional and global value chains. Consumers may purchase most of their food in local or street markets, but other supermarkets and processed food purveyors are growing as market presences. Processed and packaged foods are more accessible than under traditional food systems, while nutrient-rich foods, such as fruits, vegetables and nuts, are more expensive. A further notable change is that food advertising is pervasive, and while food labelling may appear on packaged foods, most consumers are not well informed on dietary guidelines and use of labelling to balance diets. Malnutrition, both in terms of undernutrition and overweight/obesity, occurs in intermediate or mixed food systems, with many challenges remaining on how to address these both in policy and programmes.

Current trends in intermediate (mixed) food systems include the growing importance of urban agriculture, in developed and developing countries alike. For example, urban horticulture in the Congo reaps $400 million for small growers, giving incomes, and labour and food security (FAO 2011b).

Table 3.1 Details of the key features of these food systems typologies, which serve to distinguish key elements across a complex continuum from traditional to modern

Food system feature	"Traditional' food systems	Intermediate/mixed food systems	"Modern' food systems*	Source
Estimated number of people in system	~1 billion	~4 billion	~2 billion	Ericksen (2008) UNEP (2016)
Principal employment in food sector	In food production	In food production	In food processing, packaging and retail	Ericksen (2008) UNEP (2016)
Supply chain coordination system	Ad-hoc, spot exchange	Mainly ad-hoc, spot exchange	Contracts, standards, vertical integration	Ericksen (2008), UNEP (2016)
Food production system	Diverse, mixed production system (crops and animal production) by smallholders; local and seasonal production with varied productivity and diverse benefits; low input farming systems. Food systems are the main source of energy	Combination of diverse, mixed production system and specialised operations with a certain degree of inputs, including fossil fuels, by both local smallholder farmers and larger farms often further away. Less dependence on seasonal foods	Few crops dominate (i.e. largely monoculture); specialisation and high productivity; high external inputs, including fossil fuels. Food production consumes more energy than it delivers. Overall, the system produces a wide array of foods that are available globally	Adapted from Ericksen (2008) UNEP (2016)
Typical farm	Family-based, small to moderate	Combination of smallholder farms and larger farms / fishery operations	Industrial, larger than in a traditional setting	Ericksen (2008) UNEP (2016)
Storage and distribution	Lack of adequate roads makes transporting food difficult and slow, leading to food waste. Poor storage facilities and lack of cold storage makes storing food, especially perishables, difficult	Improvements in infrastructure with better roads, storage facilities and access to cold storage; however not equally accessible, especially for the rural poor	Modern roads, storage facilities and cold storage facilitate food transport over long distances, and to store food safely for long periods of time	HLPE (2017)
Supply chain coordination system	Ad-hoc, spot exchange	Mainly ad-hoc, spot exchange	Contracts, standards, vertical integration	Ericksen (2008) UNEP (2016)
Typical food consumed	Basic locally-produced staples	Combination of basic products and processed food	Larger share of processed food with a brand name, more animal products	Ericksen (2008) UNEP (2016)

Processing and packaging	Basic processing is available such as drying fruit, milling grains or processing dairy products. Little or limited packaging occurs	Highly processed packaged foods emerge and are more accessible	Many processed packaged foods are easily available, often cheap and convenient to eat, but sometimes unhealthy	HLPE (2017)
Food bought from retail/market	Small, local shop or market	Small, local shop or market, share of supermarkets small but rapidly growing	Predominantly large supermarket chain, food service and catering (out of home)	Modified from HLPE (2017)
Nutritional concern	Undernutrition, and micronutrient deficiencies	Both undernutrition and diet-related diseases	Diet-related diseases	Ericksen (2008) UNEP (2016)
Economic access (affordability)	Food is a large portion of the household budget. Staples tend to be significantly less expensive relative to perishables (animal source food, fruits and vegetables)	Food places moderate demands on household budgets. Staples are inexpensive, whereas perishable foods are expensive. Many highly processed and convenience foods are inexpensive	Food demands less of the household budget. The price of staples is lower relative to perishables, but the difference is less stark than in the other food systems	HLPE (2017a)
Main source of national food shocks	Production shocks	International price and trade problems	International price and trade problems	Ericksen (2008) UNEP (2016)
Main source of household food shocks	Production shocks; may be more resilient than capital-intensive systems (see Altieri 2002)	International shocks leading to food poverty	International shocks leading to food poverty	Ericksen (2008) UNEP (2016) Altieri (2002)
Major environmental concerns	Soil degradation, land clearing, water shortage	Combination of concerns in traditional and modern systems	Emissions of nutrients and pesticides, water demand, greenhouse gas emissions, and others due to fossil fuel use	Ericksen (2008) UNEP (2016)
Influential scale	Local to national	Local to global	National to global	Ericksen (2008) UNEP (2016)

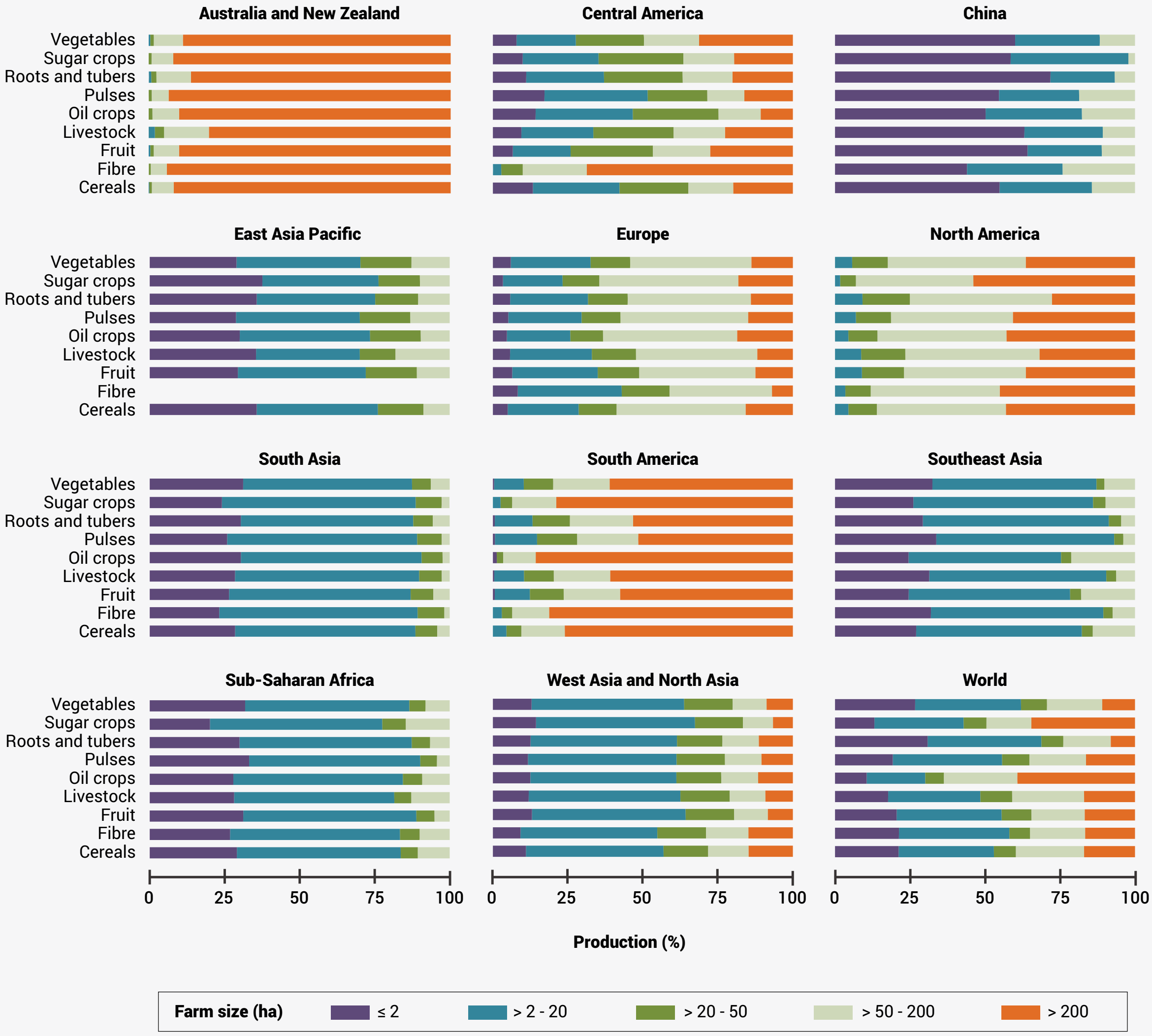
*It should be noted that the parallel trends within modern food systems as noted above - fostering agroecological, small scale and diversified systems - do not correspond to the features presented here.

3.2.3 Differential contribution of diverse food systems to global food and nutrient production

A basic typology of food systems (traditional, intermediate/mixed and modern) permits a more focused consideration of how different food systems contribute to global food and nutrient production. A key point from a recent paper by Herrero *et al.* (2017) is that understanding the differential contributions of diverse food systems is essential. Within this paper, the authors provide a breakdown not just of global agricultural production but also of nutrient production, by farm size. While there are no clear cut-offs in farm size between different food systems, small to medium sized farms tend to be found in traditional and mixed food systems, while larger industrial farms are part of modern food systems.

The Herrero *et al.* (2017) report finds that globally, small and medium farms (≤50 ha) produce 51–77 per cent of nearly all commodities and nutrients examined here, with key regional differences. As can be seen in **Figure 3.1**, small farms (≤20 ha) produce more than 75 per cent of most food commodities in the populous regions of Sub-Saharan Africa, Southeast Asia, South Asia, and China. Very small farms (≤2 ha) are important and have local significance in Sub-Saharan Africa, Southeast Asia, and South Asia, where they contribute to about 30 per cent of most food commodities. In Europe, West Asia and North Africa, and Central America, medium-size farms (20–50 ha) also contribute substantially to the production of most food commodities. Large farms (>50 ha) dominate production in North America, South America, and Australia and New Zealand. In these regions, large farms contribute between 75 per cent and 100 per cent of all cereal, livestock, and fruit production. This pattern is similar for other commodity groups.

Figure 3.1 Production of key food groups by farm size (Source: adapted from Herrero *et al.* 2017)



Herrero *et al.* (2017) also looked at how the diversity of food production changes with the diversity of agricultural landscapes and production systems. They documented that the majority of vegetables (81 per cent), roots and tubers (72 per cent), pulses (67 per cent), fruits (66 per cent), fish and livestock products (60 per cent), and cereals (56 per cent) are produced in diverse landscapes (taken as the number of different products grown within a geographic area). Similarly, the majority of global micronutrients (53–81 per cent) and protein (57 per cent) are also produced in more diverse agricultural landscapes. By contrast, the majority of sugar (73 per cent) and oil crops (57 per cent) are produced in less diverse ones (H≤1·5), which also accounts for the majority of global calorie production (56 per cent). The diversity of agricultural and nutrient production diminished as farm size increase, but regardless of farm size, it is shown that areas of the world with higher agricultural diversity produce more nutrients (ibid.).

Thus, it is evident that both small and large farms are important contributors to food and nutrition security, but very small, small and medium sized farms (found mostly in traditional and mixed food systems) produce more food and nutrients in the most populous regions of the world than large farms in modern food systems. Maintaining diverse agricultural landscapes, globally, is linked to producing diverse nutrients in viable, sustainable landscapes.

3.2.4 Inland fisheries and livestock production

Woven into the three typologies presented above are different ways of incorporating and managing the important components of inland fisheries and livestock production. The Herrero *et al.* (2017) study discussed above included seven livestock and 14 aquaculture and fish products; nonetheless, as these are often quite distinctive production systems, and a further profile of their production patterns is provided here.

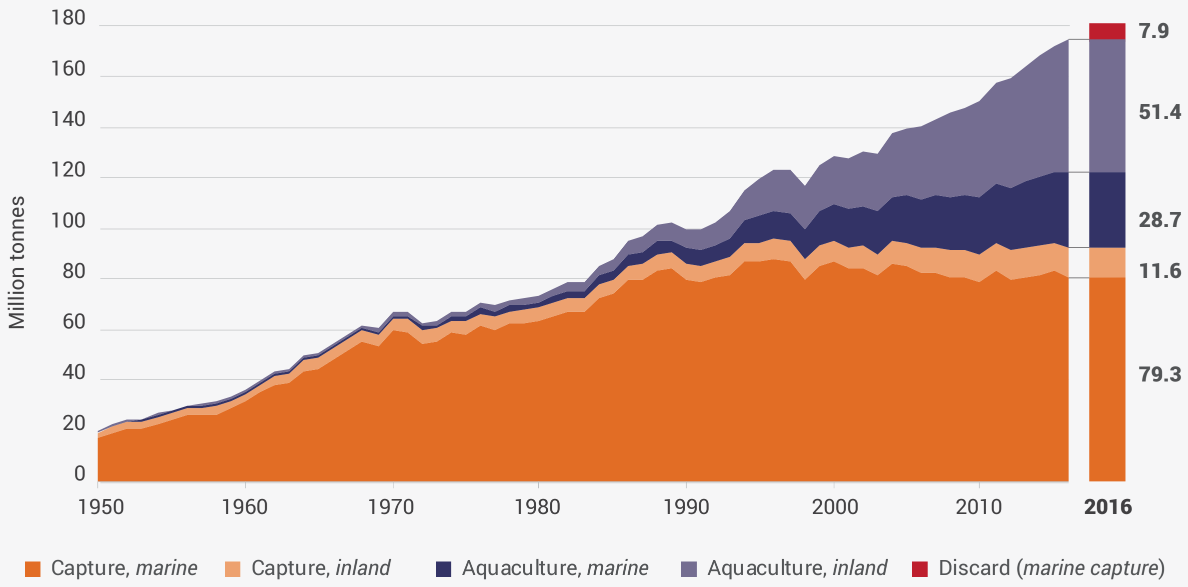
Production in **Inland fisheries**: The world's apparent fish consumption is projected to increase by 31 million tons in the next decade to reach 178 million tons by 2025. The driving force behind this increase is rising incomes and urbanization, interlinked with the expansion of fish production and improved distribution channels. Per capita fish consumption is expected to increase in all continents, with Asia, Oceania and Latin America and the Caribbean showing the fastest growth. In particular, major increases are projected in Brazil, Peru, Chile, China and Mexico. Consumption of fish will remain static or decrease in a few countries, including Japan, the Russian Federation, Argentina and Canada (FAO 2016b). While much of this production comes from wild ocean fisheries, in the last two decades, a dramatic growth in aquaculture production has boosted the average consumption of fish and fishery products at the global level. The shift towards relatively greater consumption of farmed species compared with wild fish reached a milestone in 2014, when the farmed sector's contribution to the supply of fish for human consumption surpassed that of wild-caught fish for the first time (HLPE 2014).

Although annual per capita consumption of fish has grown steadily in developing regions (from 5.2 kg in 1961 to 18.8 kg in 2013) and in low-income food-deficit countries (LIFDCs) (from 3.5 to 7.6 kg), it is still considerably lower than that in more developed regions, even though the gap is narrowing. In 2013, the per capita fish consumption in industrialized countries was 26.8 kg. In 2013, fish accounted for about 17 per cent of the global populations' intake of animal protein and 6.7 per cent of all protein consumed. Moreover, fish provided more than 3.1 billion people with almost 20 per cent of their average per capita intake of animal protein.

As noted above, capture fisheries, which includes the artisanal fisheries characteristic of traditional and mixed farming systems, contribute about 50 per cent of fish production globally, with aquaculture—as part of modern farming systems contributing the remaining half. Growth in aquacultural production, however, is increasing rapidly, while yields from capture fisheries have largely plateaued.

Inland fisheries can be separated into two categories—**capture fisheries and aquaculture systems.** Inland capture fisheries are characteristic of the artisanal nature of fisheries in traditional food systems, while aquaculture, with a growing sophistication of technology, is considered within modern food systems. As illustrated by **Figure 3.2**, with continual growth in fish production (mostly from aquaculture since the 1990s), increased production efficiency, and improved distribution channels, the world's fish production has increased almost eight times since 1950 (HLPE 2014). Inland aquaculture contributes at least 40 per cent to overall world fish production.

Figure 3.2 World fish production, 1950-2016 (Source: adapted and updated from HLPE 2014)



Livestock production: Livestock is the world's largest user of land resources. In 2013, with almost 3.4 billion hectares, permanent meadows and pastures represented 26 per cent of the global land area (i.e. the earth's ice-free terrestrial surface) (FAOSTAT). The Food and Agriculture Organization (FAO) estimates that between one-third and 40 per cent of global arable land is used to grow feed crops (FAO, global livestock environmental model – GLEAM). Together, permanent meadows, pastures and land dedicated to the production of feed thus represent 80 per cent of total agricultural land.

There are many different systems of livestock production, which enter into the food systems described here in different ways. However, as a general rule of thumb, pastoralist and smallholder livestock raising systems are found in traditional and mixed food systems.

Pastoralist systems are the result of a co-evolutionary process between populations and the environment. They have developed a variety of modes of land tenure and management that are strongly associated with mobility, the use of common pool resources and the ability of animals to convert local vegetation into food and energy. Pastoralism is globally important for the human populations it supports, the food and ecological services it provides, the economic contributions it makes to some of the world's poorest regions, and the civilizations it helps to maintain (Nori and Davies 2007; WISP 2008).

Smallholder systems include "Mixed", "Backyard" and "Intermediate" methods (HLPE 2016). These systems often combine livestock and crops on farm. They are found in all countries throughout the world, but are most heavily concentrated in Asia, Latin America and Africa. The diversified agricultural systems developed by these smallholders are often characterized by the presence of different animals and multipurpose breeds where organic farming and agroecological management integrate holistic systems. Commercial grazing and intensive livestock systems, on the other hand, are integral to modern farming systems.

Commercial grazing systems can be found both in developed and developing countries in areas covered by grasslands, but also in forest frontiers where pastures expand into forests and woodlands such as in the Amazon forest in Brazil. Latin American countries have a small number of commercial farmers who produce the bulk of agricultural production. In some regions, a smaller number of large commercial ranches co-exist with a much larger number of small farms, whereas in other countries such as Brazil, Argentina and Paraguay, large commercial ranches are the predominant land use.

Intensive livestock systems (including "Industrial" and "Feedlot" systems) are most typical in pig and poultry production and are found in all regions of the world, especially in high-income countries and emerging economies. Intensive landless systems are located around urban conglomerates of East and Southeast Asia, Latin America or near the main feed-producing or feed-importing areas of Europe and North America. Concentrated animal feeding operations (CAFOs) globally account for 72 per cent of poultry, 42 per cent of egg and 55 per cent of pork production (Harvey *et al.* 2017). In 2000, there were an estimated 15 billion livestock in the world, according to the FAOSTAT. By 2016, this figure had risen to about 24 billion, with the majority of the production of eggs, chicken meat and pork taking place on intensive farms (Harvey *et al.* 2017).

From the standpoint of diversity, however, it has been noted that the majority of vegetables, fish and livestock products (60 per cent), are produced in heterogeneous landscapes, under systems of production that provide a diversity of products and essential nutrients (Herrero *et al.* 2017)

3.2.5 Typologies of supply chains

Also interwoven into the typologies described above are diverse supply chains, spanning from a simple straight line of firms, strictly guided by the focal company, to a loose bundle of firms interacting via informal relationships and with almost no governance other than market. This section discusses six different chain typologies relevant to the agri-food sector, as seen in **Table 3.2**. Some of these typologies account for very large shares of the worldwide food markets and involve stakeholders, farmers, retailers and consumers. Others represent small market niches and are extremely dynamic.

Supply chains driven by a large retailer are found across the world and hold extremely large shares of total turnover (defined as the amount of revenue earned in a particular period) of the food sector (Carbone 2017). Their massive presence is the result of growth that has taken place at a fast pace during the last decades even in so-called 'emerging economies' and it is still ongoing (Sexton 2012). The retailers that govern the supply chain operate at a large scale and in many cases are multinational global companies.

Supply chains driven by a global processing company have a very well established reputation in final markets and usually govern the food chain in which they operate. They are usually multi-locational, global corporate companies that buy raw materials and other inputs from a large set of farms/firms that are in a quasi-captive position and are connected to the focal company mainly with vertical sequential relations.

Supply chains driven by a cooperative historically play an important role in the organization of food supply worldwide, although their nature and role varies significantly across countries. Cooperatives are themselves hybrid institutions marked by strong and stable horizontal coordination and pooled relationships. These are usually associations of farmers.

Supply chains with geographical indications (names) derive from names for traditional food referring to the location where production takes place. All the producers based in the area are entitled to sell their product with the name of the place of origin. Darjeeling Tea from India and Prosciutto de Parma from Italy are two examples.

Short chains where the focal company is a small farm or processing firm, or even a small-scale retailer, and where there are few transitions for the raw material to reach the final consumer, all mainly confined to the local markets. These are new, yet increasingly common in the modern food sector and common in mixed systems. These chains are essentially demand-driven as they respond to consumers' inclination for simple and local food that is assumed to be more genuine and fresh. Consumers associate short chains with the idea of traceable and transparent processes. Both aspects are seen under a different perspective compared to the previous chains where information is conveyed formally and codified by certifications and standards. Consumers in short chains tend to privilege and prefer face-to-face relationships that are regarded as more reliable and able to foster connections among human beings and add a personal touch to transactions. The growing proliferation of "food hubs", serving to aggregate, distribute and market local produce in the United States, are examples of efforts to create short chains.

Supply chains driven by a specialized high quality retailer are focal companies (generally retailers) that offer high quality food. Their competitive leverage and consumer appeal is the quality and provenance of their products rather than the price or affordability. Sellers offer a rich knowledge of, and intimate relationship with, small and local producers, linking them directly to the consumer (Carbonne 2017). These chains are often characterized by products that might have difficulty competing in larger markets, e.g. local, regional, traditional, ethnic, artisanal, nutritious, organic, fair trade, etc.

Table 3.2 Typologies of supply chains (Source: Carbone 2017)

Supply chains	Driving/needs keywords	Target market	Quality/ information/ trust	Innovation	Role of the place of origin	Role of farms
Large retail company	Convenience price choice	Global	Standardization certification retailer reputation/ brand	++	-	-
Global processing company	Convenience innovation differentiation	Global	Standardization trademarks/ patents producer reputation/brand	+++	-	-
Supply chain coordination system	Supply driven scale economies bargaining power	Global/local	Standardization certification coop reputation	+	++	++
Coop	Quality tradition places	Local/global high segments	GI name product specification	-	+++ (strong roots in 1 location)	++ (selling mainly processed food)
Geographical indication	Freshness genuinity environment face-to-face rel.	Local/direct personal high segments	Informal/non codified	-	+++ (strong roots in 1 location)	+++
Specialized quality retailer	Storytelling novelties culture/etnicity/ dietary/healthy environment	Global high segments	Brand/reputation of producer AND retailer	In marketing +++	+++ (sourcing from many location but origin known)	+ (selling mainly processed food)

'-' no relevant role for the correspondent chain, '+' relevant, '++' very relevant, '+++' extremely relevant

3.2.6 Spatial and cultural aspects of food systems

Key factors responsible for food system choices are peoples' thoughts around the food they eat and the multiple processes that affect food habits, linked with race, class, health, sexual orientation, social justice and history (Harper 2011). In other words, views around the way food is produced, processed and consumed are directly shaped by the degree of identity we humans connect to these diverse processes and how we link them with a "good quality of life" (IPBES 2014; Pascual *et al.* 2017a), both as producers and as consumers. Over historic time, genetic resources, but also food and feed, have been transported and exchanged among regions through time, leading to new adoptions, adaptations and uses of crops and animals.

Both of these processes – the evolution of agriculture in distinctly different agroecological zones, and the trade and exchange of agricultural resources and knowledge-have led to high **spatial diversity** in agriculture and food systems, with considerable diversification in the ways cultures around the world value and interact with their food systems. As an example, smallholder rice production systems in much of Asia have been the product of indigenous agricultural innovations and communal decisions and customs. The ancient Subak water management systems developed more than 1000 years ago for paddy rice cultivation on Bali Island, Indonesia are a premium example of this. Subak is a traditional irrigation system that has been adapted over generations to respond to ecological flows as well as cultural imperatives. It does not simply supply water to rice fields according to the ebbs and flows of seasonal rains; it is a cultural service that considers the entire water needs of the community and provides a pulsed provisioning of water to that community. The centrality of rice cultivation, both to food security and in its religious dimensions, is a strong element in many Asian cultures and influences the shape of its food systems (Lansing 2009; Marchi 2012).

The further away societies are from the primary sources of food, the more people may be detached from valuing the chosen ways of food production, processing and distribution, and the more likely they are to lack understanding and appreciation of food systems, leading to serious implications for nature. Today, this is true for a majority of human beings who live in urban areas and have unwittingly detached their reality from their food sources as well as their sense of responsibility for the ways food arrives to their plates. As Pascual *et al.* (2017a) reemphasized following the IPBES (2014) framework, *"it is critical to acknowledge that the diversity of values of nature and its contributions to people's good quality of life are associated with different cultural and institutional contexts".* This idea also applies to the existing agricultural models. Closeness and relatedness to food sources provide people with identity and the opportunity to develop an integral understanding of how food is produced and obtained and thus, it creates stronger bonds of identity in relation to the food they eat. By being detached from the food production processes themselves, we humans lose its cultural significance and knowledge and skills developed over centuries.

3.2.7 Temporal aspects of food systems: food regimes and their historical context

Food systems are often understood in a comparative, historically grounded way as food regimes. By definition, food regime is "a rule-governed structure of production and consumption of food on a world scale" (Friedmann 1993). According to McMichael (2009), the food regime concept allows us to refocus from the commodity as an object to the commodity as a relation, with definite geopolitical, social, ecological, and nutritional relations at significant historical moments. Friedmann and McMichael (1989) contend that "international relations of food production and consumption to forms of accumulation broadly distinguish periods of capitalist transformation since 1870". Food regimes are characterized by often contradictory forces of the state, business and social movements to highlight the changing role of agriculture in the development of (capitalist) world economy (Friedmann and McMichael 1989).

Bernstein (2016) defined eight key aspects of food regimes, namely: i) the international state system, ii) international divisions of labour and patterns of trade, iii) the 'rules' and discursive (ideological) legitimations of different food regimes, iv) relations between agriculture and industry, including technical and environmental change in farming, v) dominant forms of capital and their modalities of accumulation, vi) social forces (other than capitals and states), vii) the tensions and contradictions of specific food regimes, and viii) transitions between food regimes. These configurations generate stable or consolidated periods (as well as transition periods) of capital accumulation associated with geopolitical power and forms of agricultural production and consumption (McMichael 2009) (see **Box 3.1**).

Box 3.1 A brief history of food regimes

Emerging frameworks for understanding sustainable food systems are to some extent based on history - where we have been and where we may be going. The Food Regime Theory of Friedmann and McMichael (1989) traces the legacies of previous "food regimes" – starting with those from the late 1800s to 1930 in which family labour and its contribution to export agriculture underwrote the growth of food markets and nation-state systems. The period of 1950 to the 1970s witnessed a second regime comprised of the extension of the state system to former colonies, and the restructuring of the agricultural sector by agri-food forces. The authors suggest that two complementary alternatives are now possible choices to transform food systems: i) global institutions capable of regulation of accumulation, and ii) the promotion and redirection of regional, local and municipal politics deriving from decentralized ideologies. More recent articulations of the current "food regime" (McMichael 2009) continue to note the inherent contradictions as corporate food regimes embrace environmental dimensions, with the risks that "green capitalism" fosters new forms of accumulation by appropriating the demands of environmental movements. The key counterweights to such accumulations of power are seen as social movements, such as Food Sovereignty or Fair Trade Movements and others from the Global South. These perspectives demand that we address the "externalities" in food regimes (Biovision and Global Alliance for the Future of Food 2018), "embracing a holistic understanding of agriculture that dispenses with the society/nature binary, and politicizes food system cultures" (Friedmann and McMichael 1989).

3.3 CHALLENGES AHEAD FOR THE WORLD'S AGRICULTURE AND FOOD SYSTEMS

Various external forces and "lock-ins" reinforce forms of food production that neglect the contribution or negatively impact nature and harm human welfare. The impacts include widespread degradation of land, water and ecosystems; high greenhouse gas emissions; major contributions to biodiversity losses; chronic over and under malnutrition and diet-related diseases; and livelihood stresses for farmers around the world (IPES-Food 2016).

In this section, we will look at economic pressures and external forces that pose challenges to sustainable agriculture, and then explore pathways to viable solutions. Throughout, we will seek to highlight those invisible and visible flows in the food system that are the focus of the TEEB perspective.

Too often the analysis of agricultural systems focuses on production while paying far less attention to subsequent steps such as transformation, transportation, distribution, consumption and recycling. This is a serious problem since most of the economic benefits are concentrated in the stages after biomass production. The segmented approach also does not allow an analysis of materials and energies used in the food chain, and the interactions between them. The TEEBAgriFood Evaluation Framework, this chapter, and other sections of this report address the different value-chain stages, incorporating the visible and invisible flows of different indicators (quality and quantity indicators).

3.3.1 Economic pressures and external forces around agricultural and food systems transitions

Models of agricultural development: For many decades, developing countries have been encouraged to follow the path of industrialized countries by undergoing a "structural transformation" from having large, low-productivity traditional agricultural sectors to more industrialised agricultural sectors as a precursor to a modern industrial economy with high productivity (Byerlee *et al.* 2009) and an expanded service sector (Dorin 2017). More recent models consider agriculture not merely as the facilitator of industrialization but as central to development itself. Nonetheless, productivity remains central to the predominant economic models for growth and development, fed by increases in land and labour productivity in agriculture. Tensions in this model are apparent in many regions. For example, the majority of African countries have limited arable land resources with high population pressures. Yet most projections for substantial yield increases earmark African countries as the locale where these increases are most needed. Current yield gaps in Africa are both pervasive and complex, with clear biophysical limitations but also issues that call for greater attention to social contexts (Tittonell and Giller 2013; Mapfumo *et al.* 2015), diversification and infrastructure investment (Van Ittersum *et al.* 2016). Large-scale land purchasing by foreign investors or "land-grabbing" is also a problem in Africa (UNEP 2014). Thus, both land and labour are under conflicting economic pressures in the agriculture sector, as we review below.

Labour and employment in the food and agriculture sector: The agricultural sector employs one out of every three economically active workers (FAO 2014). **Figure 3.3** shows that, as countries develop, the share of the population working in agriculture declines. While more than two-thirds of the population in poor countries work in agriculture, this percentage decreases to less than 5 per cent in rich countries (Roser 2018).

In developing countries, labour in the agricultural sector is a key area of focus for current and future economies. There are 1.5 billion smallholder farmers, and an estimated 500 million family farms, i.e. those that are managed and operated by a family and predominantly reliant on family labour globally (FAO 2014). These family farms make up more than 98 per cent of the world´s farms (Graeub *et al.* 2016).

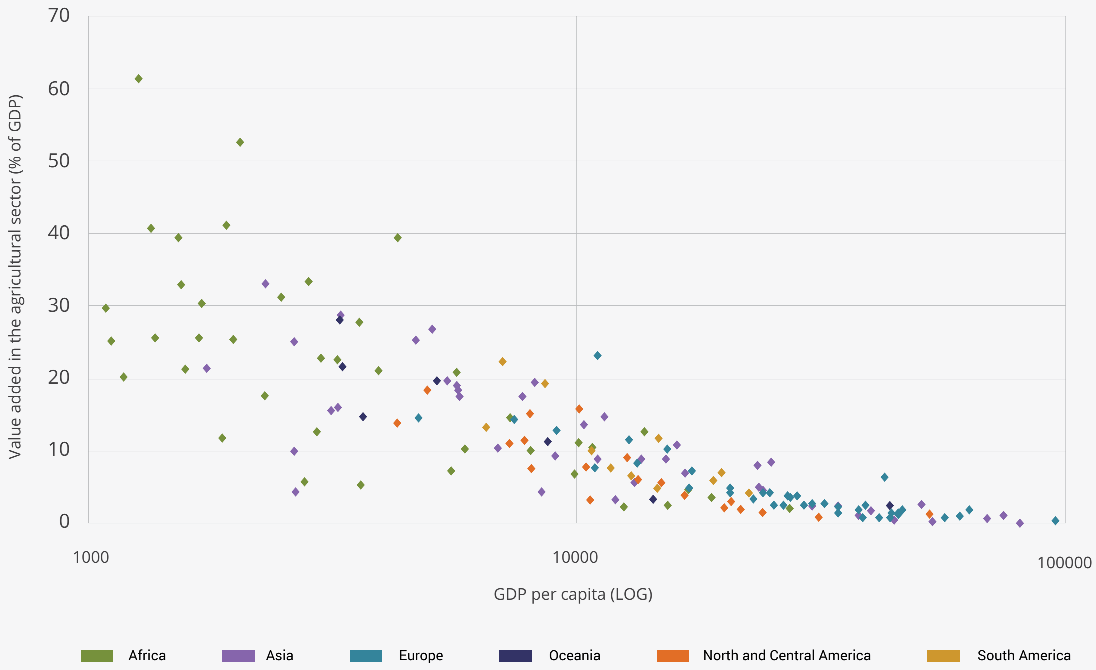
With this in mind, new voices are suggesting that the "structural transformation" trajectory is not and will not be a reality in much of the developing world (Dorin 2017). As has been true in India, it is highly plausible that the rural population and labour force in agriculture in Africa (and India) can be expected to remain massive through the next few decades. These findings require a reconsideration of the "modern" model of increasing land and labour productivity in agriculture. In view of the size of the rural labour force, it has been argued that increases in agriculture in these regions should not rest on large scale monocultures and intensive use of inputs, but rather on a context-specific agroecosystems that build biological synergies and boost biodiversity and ecological functions to increase and sustain productive growth in multiple dimensions, delivering multitude of long-term benefits (Dorin 2017). Certainly, finding sustainable means to increase access, availability, utilization and stability of food is critical to both avoiding deforestation and addressing food security in many developing countries.

An overriding challenge and concern in developing and developed countries alike is the eroding profitability of farms, with farming professions ceasing to provide a living wage and viable livelihoods within rural communities. As noted by Buttel (2007) the practice of farming has for many decades been in the grips of a "profitability squeeze", undermining social, economic and environmental sustainability. In developed countries such as the US, net farm incomes have declined consistently and dramatically since 1948, a trend that has to some degree been lessened in severity through the application of subsidies. Such resources and public policies are not available to lessen the severity of declining and volatile profitability in agriculture for farmers and communities in developing countries.

Investment and land demand and supply: Altogether, worldwide foreign direct investment in agriculture has increased significantly since 2000, especially in developing countries, reaching more than 3 billion USD per year since 2005 (UNCTAD 2009). However, global foreign direct investment flows lost growth momentum in 2016, showing that the road to recovery remains bumpy (UNCTAD 2017). FDI inflows decreased by 2 per cent to $1.75 trillion in 2017, amid weak economic growth and significant policy risks, as perceived by multinational enterprises (UNCTAD 2017). Agriculture and food systems have been particularly impacted by land grabbing, the large-scale land acquisition—be it purchase or lease—for agricultural production by foreign investors. In the three years from 2007 to 2010 for example, more than 20 Mha are thought to have been acquired by foreign interests in Africa (Hallam 2010). Several countries are now changing rules for direct foregoing investors. Argentina eased certain restrictions on the acquisition and leasing of rural lands by foreign individuals and legal entities. Malawi lifted a ban on oil and gas exploration in Lake Malawi. Myanmar introduced the new Condominium Law, permitting foreigners to own up to 40 per cent of a condominium building. Poland adopted new restrictions for the acquisition of agricultural and forest land and for purchasing shares in Polish companies that have agricultural property (UNCTAD 2017). The discussion of foreign investment in and purchase of land is on the table and is generating deeper consideration of benefits and costs.

While the concept of acquiring land abroad to pursue economic interests is not new, this new type of land grabbing may also lead to violations of human rights (Rosset 2011) and environmental consequences which directly counteract the commitments of countries made to eradicate such occurrences (as in the case of the Millennium Development Goals). Early experiences with biofuel production in countries like Tanzania, Mozambique, India and Colombia have been characterized by land purchases marked by illegitimate land titles, water access denied to local farmers, inadequate compensation agreements, and displacement of local communities by force (Cotula *et al.* 2008; 2009). In Argentina, 14 million hectares have been sold with consequences for rural peasants, indigenous people and even completed towns that have been sold to individuals or companies (Pengue 2008). Such projects often do little to improve regional food or energy security. Because of the industrial, high-tech agriculture that land grabbing favours, it often means a step backward for peasants or small farmers and sustainable agriculture. This contradicts authoritative international recommendations, which see the support of smallholder agriculture as a fundamental effort in the struggle against hunger (UN Human Rights Council 2010). Displacing local producers and diverting resources to cash crop production may increase the vulnerability of local communities to the volatility of food prices.

Figure 3.3 Relationship between participation in agricultural sector and GDP per capita, 2015 (Source: adapted from Roser 2018)



Investment in biofuel and biomass: Investment in the biomass sector is a growing issue, increasing the demand for land practically all over the world. This demand is not only related to food production but also includes demand related to animal feed, biomass, biomaterials and others. As the intention of biofuel projects is to later export the fuel, this does little to substantially improve the energy situation in the country of production. For instance, roughly two-thirds of Mozambique is without electricity, but even projects intending to keep 20 per cent of the ethanol produced within the country are unlikely to contribute to the amount of electrification needed to improve living conditions (FIAN 2010).

Subsidies and distorting fiscal measures along the value chain: Due to the rapidly increasing productivity in major OECD countries in particular, the 1970s and 1980s were characterized by domestic overproduction of food, resulting in domestic surpluses. The subsidized export of these surpluses tended to depress world prices, affecting agriculture production in other countries. Distortions in global markets reached a peak in the 1980s, with overproduction of food in the European Union (EU) and an export/subsidy war between the United States of America (USA) and the EU further depressing agricultural prices in low- and middle-income markets (UNEP 2016), thereby affecting millions of farmers in developing countries and their markets. Despite these negative impacts, OECD countries have continued to pursue policy measures that promote the intensification and overproduction of food commodities, and the liberalization of trade to facilitate export to more vulnerable developing economies.

Distortions in global markets create social, economic and environmental impacts. Some discussion of the nature of current subsidies in the agriculture sector is provided here, while recognizing that the subject is complex and the analysis of impacts is very challenging. By way of a simplified explanation, perverse subsidies tend to create distortions in the global market and can lead to more overexploitation of natural resources and human resources. Globally, the tendency for subsidies to encourage the intensification of production at the cost of the environment (negative externalities) has been noted, but largely ignored. If global farm subsidies were ended and agricultural markets deregulated, different crops would be planted, land usage would change, and some farm businesses would contract while others would expand (Edwards 2016). Where subsidies are underwriting farming with highly negative externalities, the withdrawal of this support would result in different crops being planted, land usage changing away from such systems, and some farm businesses contracting while others would expand. The absence of deleterious subsidies could contribute to a stronger and more innovative industry. New relationships in the food system could emerge that have greater resilience to market fluctuations (Edwards 2016). Private insurance, other financial tools, diversification, and payments to farmers to recognize their role in protecting the environment could help cover risks, as they do in other industries and small and midsized farmers and peasants would find a clearer connection between their labour and prices and a greater recognition of their efforts.

Consolidation in the food sector: A number of external forces have increasingly impacted global food systems in recent decades. The introduction of neo-liberal modes of governance, globalization, de-regulation, privatization, the establishment of WTO rules for agriculture, and the increase in the size and influence of financial institutions have all contributed to the dismantling of the state-centred national agricultural development models (Barker 2007). These have been supplanted by privatized agricultural systems (marked, for example, by the dismantling of state marketing boards), structured to service global markets and rapidly expanding trade (Barker 2007). At the same time, the information technology revolution has transformed logistics, leading to the expansion of globally traded foodstuffs, fertilizers and pesticides possible on scales that would have been unimaginable in the mid-20th century. The biotechnology industry has enabled the commercialization of genetically modified organisms (GMOs) with strong proprietary rights. As a result of these developments, an unprecedented level of consolidation is occurring in the food sector globally (IPES-Food 2017).

Since the elimination of most public commodity stock-holding programmes in big exporter countries – Argentina, Canada, New Zealand, including the USA and the EU (a gradual process that started in the 1980s) – the international firms involved have themselves begun to hold more physical stocks. The existence and control of these physical stocks can have an important impact on grain prices, and information about them is likely to be very important in guiding these firms with respect to their financial investments in agricultural derivatives markets. In this way, the storage function of the large global agribusiness firms is tightly integrated with other aspects of their business activities.

Trade in any commodity is characterized by risk. Any number of factors – natural disasters, crop failures, political or economic shifts, market speculations – can affect the prices of agricultural commodities, which may be locked into a long supply chain. While prices can change quickly, commodity traders are dealing with a physical stock that is bulky, expensive to store, and harvested only at certain periods of the year. Prices are as much about anticipated supply and demand as they are about existing conditions. The level of risk and volatility in the trading of standardized and generic products pushes the companies to look for strategies that will increase their stability and predictability.

Overall, the period of high prices and high volatility appears to have served financial interests of the large global agribusiness firms well, though they have lost money in some areas too, and all suffered in 2009 following the financial crisis and the collapse in international trade. Disruptions to commodity markets in 2010, including the Russian export ban, created opportunities for grain trading firms to profit from food price shifts (Murphy *et al.* 2012).

International trade and trade policies: International trade and trade policies affect the domestic availability and prices of goods and also affect factors of production such as labour, with implications for food access. International trade can also impact market structure, productivity, sustainability of resource use and nutrition among various population groups in different ways. Assessing trade's impact on food security is thus highly complex. For example, banning grain exports can boost domestic supplies and reduce prices in the short run. This benefits consumers, but has negative implications for farmers producing for export. Import or export restrictions by major players affect global supplies and exacerbate price volatility at the global level. Lowering import duties reduces food prices paid by consumers, but can put pressure on the incomes of import-competing farmers, whose own food security may be negatively affected (see **Table 3.3**).

Policies to increase openness to international trade have generally taken place in the context of wider economic reforms, and it is therefore difficult to disentangle their effects.

Table 3.3 The possible effects of trade liberalization on dimensions of food security (Source: adapted from FAO 2015a)

	Possible positive effects	Possible negative effects
AVAILABILITY	Trade boosts imports and increases both the quantity and variety of food available. Dynamic effects on domestic production: Greater competition from abroad may trigger improvements in productivity through greater investment, R&D, technology spillover.	Food net-exporting countries, higher prices in international markets can divert part of production previously available for domestic consumption to exports, potentially reducing domestic availability of staple foods. For net food-importing countries, domestic producers unable to compete with imports are likely to curtail production, reducing domestic supplies and foregoing important multiplier effects of agricultural activities in rural economies.
ACCESS	For net food-importing countries, food prices typically decrease when border protection is reduced. In the competitive sectors, incomes are likely to increase as the result of greater market access for experts. Input prices are likely to decrease. The macroeconomic benefits of trade openness, such as export growth and the inflow of foreign direct investment, support growth and employment, which in turn boosts incomes.	For net food-importing countries, the domestic prices of exportable products may increase. Employment and incomes in sensitive, income-competing sectors may decline.
UTILIZATION	A greater variety of available foods may promote more balanced diets and accommodate different preferences and tastes. Food safety and quality may improve if exporters have more advanced national control systems in place or if international standards are applied more rigorously.	Greater reliance on imported foods has been associated with increased consumption of cheaper and more readily available high calorie/low-nutritional-value foods. Prioritization of commodity exports can divert land and resources from traditional indigenous foods that are often superior from a nutrition point of view.
STABILITY	Imports reduce the seasonal effect of food availability and consumer prices. Imports mitigate local product risks. Global markets are less prone to policy- or weather-related shocks	For net food-importing countries, relying primarily on global markets for food supplies and open trade policies reduces the policy space to deal with stocks. Net food-importing countries may be vulnerable to changes in trade policy by exporters, such as export bans. Sectors at earlier stages of development may become more susceptible to price shocks and/or import surges.

Financialization of the food system entered a speculative mode beginning in the 1990s, when the deregulation of commodity futures trading in the United States made it possible for institutional investors to enter this market on a large scale. Since then, on the world's most important futures exchange CBOT in Chicago, the percentage of commercial traders has decreased remarkably, while the number of speculative traders has exploded. In 2002, eleven times the actual amount of wheat available was traded on the CBOT; in 2011, 73 times the actual US wheat harvest was traded (Global Agriculture 2017). Although these speculative deals in food commodities are generally oriented towards the real situation of supply and demand, the psychology of the stock exchange and the algorithms of the computers that control the trade have led to increasingly nervous fluctuations. According to many analysts, the investors who bet on long-term increases in food prices are now having a price-driving effect (Global Agriculture 2017).

A handful of global corporations now organize the world's agriculture and food-consumption patterns. They are remarkably long-lived: many of today's leaders were founders of the modern agri-food system. This has led to two major developments – a shift towards finance capital and the impact of biotechnologies – that have led to a wave of mergers and acquisitions since the 1980s, changing the face of the sector and transforming financing in agriculture (HBF 2017).

3.3.2 Responses to economic pressures and external forces in global agriculture and food systems

The economic pressures and external forces described above have exerted significant changes, especially over the past fifty or so years, on the nature of food and farming. In this subsection, we will highlight these challenges, which impact production systems and the global environment (as well as nutrition and human welfare, which are featured in subsequent chapters of this report).

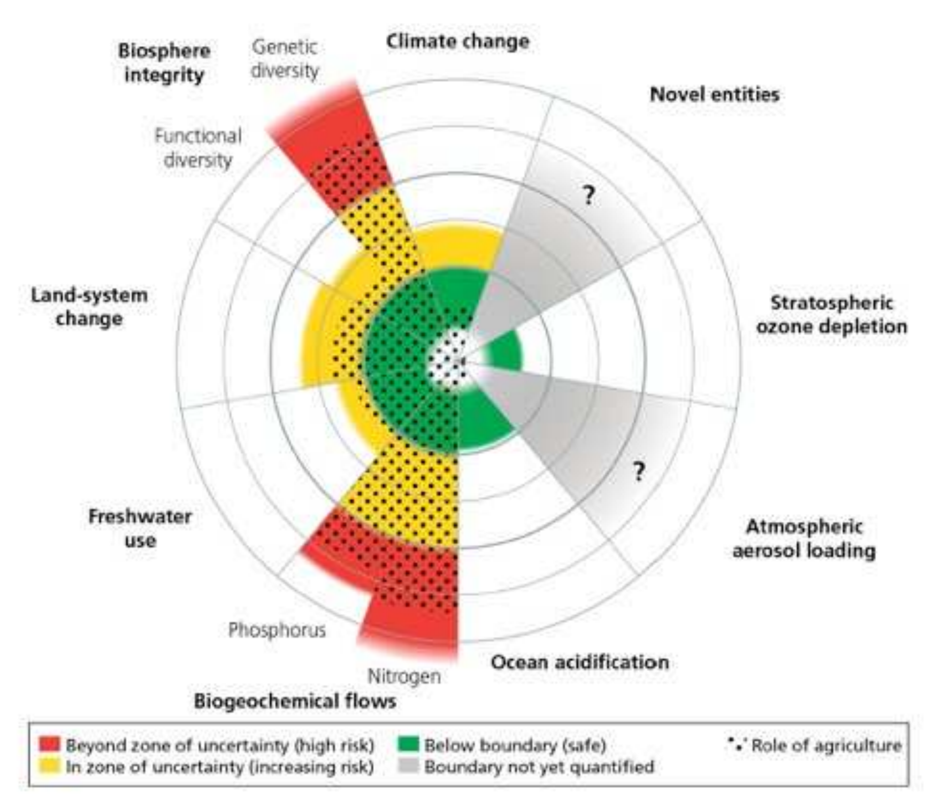
Move away from use of renewable resources: Human domination of the terrestrial space has grown enormously, to the point that agricultural systems occupy much of the geographic space available to produce biomass to sustain flora, fauna and human populations. Croplands and pastures are estimated to be one of the largest terrestrial biomes on the planet, occupying~40 per cent of land surface (Foley *et al.* 2005), making agricultural production the planet's single most extensive form of land use (Campbell *et al.* 2017).

Agriculture is inherently a resource-intensive enterprise (Campbell *et al.* 2017). As agriculture has expanded in land area, so has its environmental impact. **Figure 3.4** shows that, in multiple dimensions, agriculture is contributing substantially to destabilizing key Earth processes at the planetary scale: land-system change, biosphere integrity, biogeochemical flows, biosphere integrity, and freshwater use have all been impacted to some degree (ibid.) Currently, degradation of the Earth's land surface through human activities is negatively impacting the well-being of at least 3.2 billion people, pushing the planet towards a sixth mass species extinction, and costing more than 10 per cent of the annual global gross product in loss of biodiversity and ecosystem services (IPBES 2018a).

To a large extent, these destabilizing forces have arisen as agriculture has increasingly moved away from its dependence on natural processes and renewable resources towards non-renewable resources. For example, biogeochemical flows have been profoundly transformed as farming systems have discarded traditional means of maintaining soil fertility (through fallowing, integrating livestock with crops, and use of composted material) in favour of increased use of fossil-fuel-based and mined fertilizers. Similarly, stratospheric ozone depletion is linked to increasing rates of N_2O emissions (associated with nitrogen fertilizer application and manure from confined livestock operations). Concentrations of half the pesticides detected in freshwater aquatic systems currently exceed regulatory thresholds, a consequence of the high dependence in many agricultural systems on agrochemicals rather than natural pest control (Campbell *et al.* 2017). The tremendous increases in productivity over the last half century, propelled by the external forces of international markets and competition over land among others, have come with a number of costs, including stability and consistency of food security for many stakeholders.

Current trajectories have been driven by imperatives to increase both efficiency and productivity. Many observers note that there is an equal imperative to reduce the environmental impacts of these trajectories. Given the need to simultaneously address productivity, sustainability and equity, solutions will be complex.

Figure 3.4 The status of the nine planetary boundaries overlaid with an estimate of agriculture's role in that status (Source: Campbell *et al.* 2017)



Recent analyses of agricultural and environmental trends suggest that the environmental footprint of agriculture can most effectively be addressed by avoiding further expansion into natural ecosystems, increasing the efficiency of inputs, and improving soil health (Clark and Tilman 2017). Of these, reducing expansion into natural ecosystems seems imminently possible, given that agricultural production in developing countries has increased by about 3.3 per cent per year over the last two decades, while agricultural land area increases due to deforestation have been on a much smaller order, of .3 per cent (Angelsen 2010), reversing earlier trends (Gibbs *et al.* 2010). At the same time, it should be noted that these positive global trends mask differences between tropical deforestation, which has accelerated since the 1990s while temperate forest cover has remained stable or grown (Kim *et al.* 2015), pointing to the need to address all approaches simultaneously. Approaches to improve input efficiencies and build soil health are measures that build on ecosystem services, of great relevance to this report (see Section 3.4.1 on the interdependence of nature and agriculture).

The impact of loss of connections to local communities: Agricultural systems have also lost many of their connections to local communities, as they have become - in some regions - monocultures oriented to external markets through the purchase of industrial inputs to sell commodities for profit (FIAN 2009). Many modern agricultural systems have ceased to use local labour, and dispensed with the benefits received from biodiverse landscapes, creating a loss of regional environmental services. Resulting problems such as deforestation, soil erosion, biological species loss, toxic contamination, greenhouse gas emissions, and rural migration have arisen.

Impacts of food prices on the dynamics of food systems: The dynamics of food systems are a complex issue, strongly influenced by market and international prices. Food prices in turn are driven by a complex combination of factors. The investment of international capital in food and agriculture has major implications for the distribution and cost of food. Financial institutions and instruments have become increasingly involved at all points of the agri-food system. When average prices of (food) commodities increase, this gives rise to growing speculation (e.g. by trading of futures) (UNEP 2014), which may also result in price spikes. Fluctuating prices are a core problem for stable food production. Agricultural price volatility increases the uncertainty faced by farmers and affects their investment decisions, productivity and income. Instability in prices is a complex factor in the agricultural domain as well as in biomass processing and consuming sectors.

The markets around biomass can serve as an example. Biomass– defined as energy obtained by burning wood or other organic matter – has been a part of human societies for millennia. But recently biomass has become an internationally traded commodity for use not only as food and feed in agroindustry, but also as biofuels and biomaterials. The growing demand for food, feed and fibre exerts additional pressure on suppliers and consumers through higher level and volatility of prices, compromising food security (in particular for the poor, as happened in 2008). Growing prices of food and non-food biomass render productive land a more precious asset and have encouraged private and state investors to realize larger land purchases in low cost countries with often less favourable social and environmental controls.

Consumer behaviour, changing diets and new trends: The combination of rising income and urbanization is changing the nature of diets (Msangi and Rosegrant 2009) and thus food systems. While the consequences are dealt with in more detail in Section 3.3.7, here we outline the major trends and pressures in both urbanization and diet changes.

Urbanized populations consume less basic staples and more processed foods and livestock products (Rosegrant *et al.* 2001). This implies more potatoes for fast food, more oilseeds for feed and more sugar for food processing and manufacturing (Fischer *et al.* 2009; OECD and FAO 2010). UNEP (2013) predicts that 4 billion more urban dwellers will live in developing world cities between 1950 and 2030, in what might be considered a "second wave of urbanization". This "wave" now underway promotes a major transformation of demand for environmental, natural resources and ecosystem services from urban areas. Processed, prepared foods may require a higher use of agricultural commodities to create a given number of calories (von Witzke and Noleppa 2010), and meat consumption requires pastures for grazing and cropland for growing feed. The expansion of agricultural land has happened at the expense of natural ecosystems.

Projections on food production (both calories and nutrition) increases needed over the next several decades are often contested (Meyfroidt 2017), although a few key points are emerging around which there is a fair amount of agreement. The productionist argument, that the amount of food produced globally will need to double (Tilman *et al.* 2011), or increase by 70 per cent (FAO 2009), or by 60 per cent (Alexandratos and Bruinsma 2012) has been tempered by the realization that clean water and sanitation, and female education have been responsible for 68 per cent of the reduction in child malnutrition (between 1970 and 2010 in a longitudinal study across 116 countries), while increased food supply accounted for only around 18 per cent (Smith and Haddad 2015). A recent parsing (Chappell 2018) lays out the logic to suggest that we currently produce almost enough food on a calorie basis for the estimated 9.14 billion people projected for 2050, even with no changes to diet or waste. Thus, meeting global needs in the future might best focus on changes in production systems that might conceivably slightly reduce yields in some regions to favour environmental benefits, but more generally address yield gaps through ecosystem services while focusing on diets and reducing food waste. Increasingly, the focus is on the nutritional quality of food produced, noting that the spectacular production increases of the last half-century have come from high-yielding and not nutrient-dense cereals, such that more food needs to be consumed to attain recommended dietary levels for many nutrients than in the past (DeFries *et al.* 2015).

Much of the structural change in diets is occurring in developing countries, as diets in developed countries are already high in processed foods and livestock products. For instance, the three food groups of livestock products (meat, milk, eggs), vegetable oils and sugar currently provide around 29 per cent of total food consumption in developing countries (in terms of calories). If current trends continue, their share is projected to rise to 35 per cent in 2030 and 37 per cent in 2050, whereas their share in industrial countries has been around 48 per cent for several decades (Alexandratos and Bruinsma 2012). In 2008, 80 kg per capita of meat was consumed in developed countries in 2008, compared to 29 kg in developing countries (Alexandratos 2009). Projections for 2050 carrying forward current trends expected an increase to 103 kg in the former and 44 kg in the latter (FAO 2006). However, a more recent revision of these estimates suggests that not all developing countries – such as India – will shift in the near future to levels of meat consumption typical of western diets, and thus the estimates of how much the growth of world food production will be required to increase to meet demands have been revised downward (Alexandratos and Bruinsma 2012).

Altogether, the projections for world food consumption predict an increase of about 10 per cent in the global average caloric intake per person from 2005 to 2050, along with projected increases in population numbers. In 2009, around 5 per cent of the population was still expected to be chronically undernourished by 2050 (Alexandratos 2009); three years later this figure was modestly revised to estimate 4 per cent of the population (Alexandratos and Bruinsma 2012). Bruinsma (2009) has forecast an increase of 71 Mha of arable land needed to meet these rising food and feed demands. A 12 per cent expansion is predicted in developing countries, especially in sub-Saharan Africa (64 Mha) and Latin America (52 Mha), whereas a 6 per cent decline is expected for developed countries. While Fischer *et al.* (2009) also forecasts a 12 per cent increase in cultivated land in developing countries, he estimates an overall increase of about 124 Mha between 2010 and 2050. Neither scenario considers biofuels, biomaterials and changing demands from other industries.

Changing diets implies a shift from vegetable protein to animal protein. This "battle for the protein" (plant-based foods vs. animal-based foods) is changing the face of the earth (Pengue 2005). If current trajectories continue, a more diverse food production model will be replaced by the extensive cultivation of feed crops for animals, largely destined for Europe and China. As a result, poor people will no longer produce or be able to afford the diverse diets they once enjoyed: traditional diets with reasonable portions of high value meat protein grown on less intensive pasture will increasingly be displaced by cash crops such as soybean (Rosin *et al.* 2013) destined for animal feed.

3.3.3 Externalities and invisibles: global costs of global food trade

For centuries, countries have relied on trade in agricultural and food commodities to supplement and complement their domestic production. The uneven distribution of land resources and the influence of climatic zones on the ability to raise plants and animals have led to trade between and within continents.

Trade, in itself, is neither a threat nor a panacea when it comes to food security, but it can pose challenges and risks that need to be considered in policy decision-making. To ensure that countries' food security and development needs are addressed in a consistent and systematic manner, policy makers need to have a better overview of all the policy instruments available to them and the flexibility to apply the most effective policy mix for achieving their goals (FAO 2015a).

Moreover, the hidden costs of the global food trade are largely not known or recognized by policy makers. It is such externalities and invisibles that are a focus of true cost accounting in agriculture and food, and thus this report.

Externalities generally refer to the social or economic costs that are not recognized within financial transactions. Externalities, defined as *"a positive or negative consequence of an economic activity or transaction that affects other parties without this being reflected in the cost price of the goods or services transacted"* These may be either negative (such as pollution by nitrogen run-off from crops) or positive, such as the pollination of surrounding crops by bees kept for honey.

Several of the externalities in the agriculture sector are directly related to international trade in agricultural and food production. Agriculture and food consumption are identified as one of the most important sources of negative externalities, creating serious environmental pressures on natural habitats, land use change, climate, water use and air quality (UNEP 2010).

As international trade in food and feed products has increased, insidious forms of visible, and invisible, flows are occurring. For each shipment of food being transported from one part of the world to another, the natural resources used in the production of each shipment is also, in a sense, being "virtually" transferred to the recipient country. Essentially, the evolution of international trade has facilitated the transfer of resources from the centres of supply to the centres of demand. The inequities involved in such transfers have been noted. An "Ecological Prebisch" analysis (as articulated in Pérez-Rincón 2006) follows on the thesis of the famous economist Prebisch, that the gains of international trade and specialization have not been equitably distributed and that in the current century there is an unequal international ecological exchange (natural resources/environmental services/ecological impacts) in the global trade matrix.

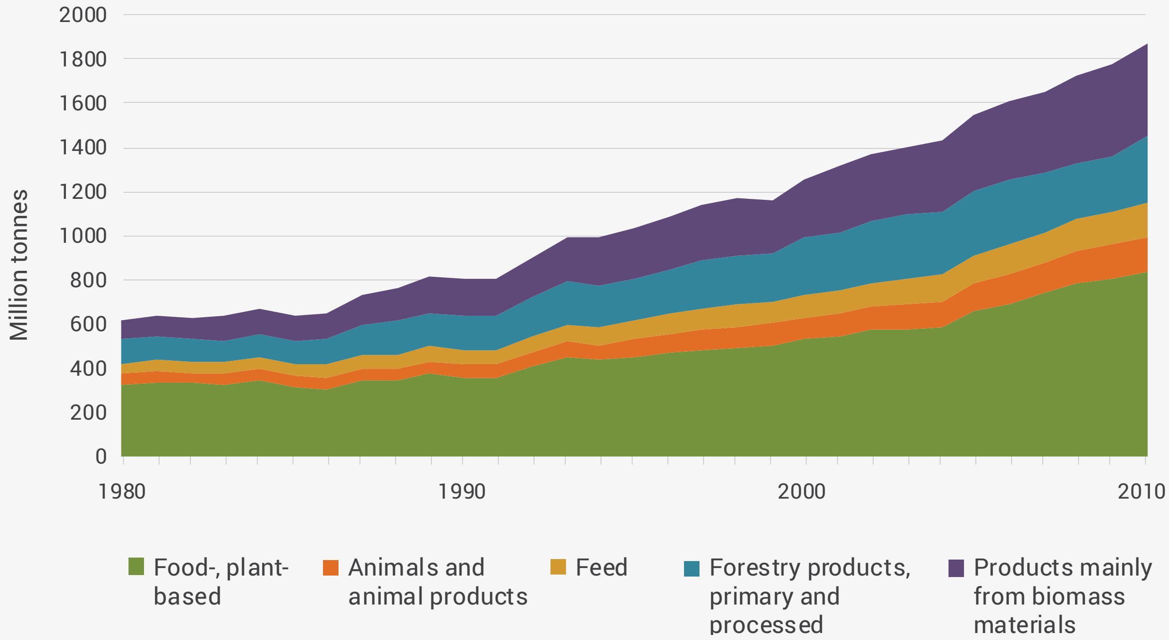
These same dynamics are identified in the concept of "off-stage" ecosystem service burdens, recognizing that many place-based analyses ecosystem assessments overlook the distant, diffuse and delayed impacts of current economic systems, including the increased reliance on final and embedded imports and exports of natural resources in the sectors of food and fisheries (Pascual *et al.* 2017b; Liu *et al.* 2013), particularly through the commodity supply chains of high income and high price-elasticity crops (Meyfroidt 2017).

As a result of these analyses, indicators such as "material footprint", "water footprint" or "nutrients footprint", have emerged and allow the characterization of material (or carbon, or water, or land and soils) consumption levels of individual countries, including the upstream flows used to produce respective imports and exports (Hoekstra and Wiedmann 2014; Tukker *et al.* 2014; Wiedmann *et al.* 2015). These upstream material requirements are also known as, 'materials embodied in trade', 'indirect flows', 'hidden flows', 'virtual flows' or 'ecological rucksacks'. Indicators for upstream resource requirements should capture resource use along the production chain and allocate environmental burden to the place of consumption. Beyond directly traded masses, upstream flows provide insights into the overall physical dimension of trade.

Biomass: Biomass can serve as a case in point. In 1900, biomass was still the major resource used by societies, as a source of nutrition as well as for construction and energy provision (Dittrich 2012). Global biomass use stood at 5 billion tons in 1900 (Krausmann *et al.* 2009), which represented 75 per cent of all material use. By 2010, biomass trade had increased to 21 billion tons.

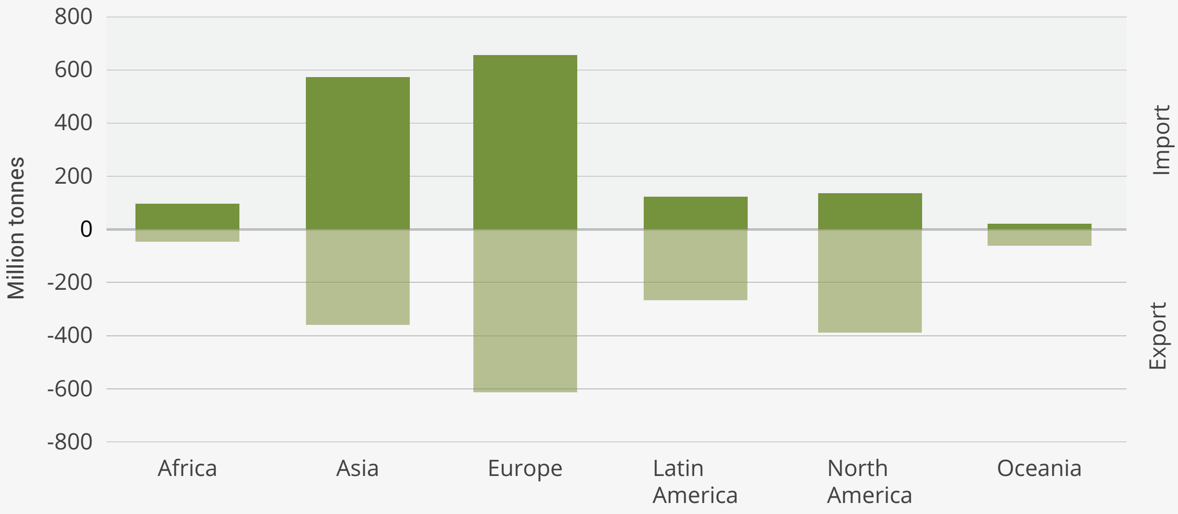
Overall, around 15 per cent of all biomass materials globally extracted are redistributed through foreign trade (UNEP 2015). Biomass materials are homogeneous in terms of their chemical composition [hydrocarbons] but still comprise different materials. The major share of biomass use comprises crops (36 per cent, cereals, vegetables, roots, fruits, etc.) and crop residues (20 per cent, mainly straw and beet leaves), followed by fodder crops (6 per cent), grazed biomass (26 per cent) and timber (11 per cent). Fish catch is relatively small, compared to total biomass extraction, amounting to only 0.4 per cent (UNEP 2015). **Figure 3.5** and **Figure 3.6** show the extent of trade by commodity and by country, respectively.

Figure 3.5 Trade in biomass by main sub-category, 1980-2010 (Source: adapted from Dittrich 2012)



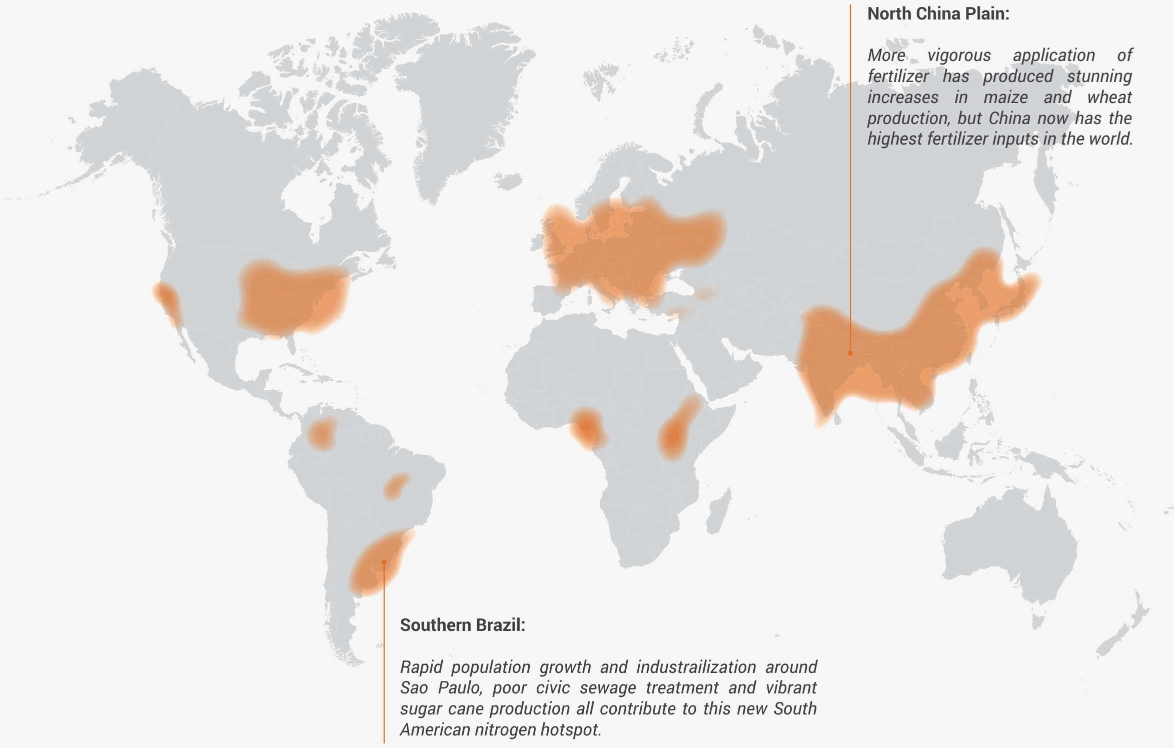
Note: trade is based on exports, because export statistics of biomass are more complete in terms of country and commodity, and have a better coverage than imports.

Figure 3.6 Biomass-based commodity trade between countries (Source: adapted from Dittrich 2012)



As biomass is transported in large volumes across the world, the underlying agricultural production acts like a "mining" process in several parts of the world. Biomass production requires large amounts of the nutrients N, P and K, amongst other nutrients (oligo and micronutrients), to provide the building blocks of all plant and animal life. Countries with substantial farming activities tend to use intensified farming practices, which extract nutrients from soils. To balance this, modern conventional farming enterprises generally increase the use of NPK inputs in fertilizers (Liu *et al.* 2010). If nutrients are not replenished, then soils become depleted and plant growth is restricted. This soil exhaustion represents a 'hidden cost' or environmental intangible (Pengue 2009), since nutrients exported from soils as natural capital remains unaccounted for (Díaz de Astarloa and Pengue 2018). Agricultural intensification and mining soils, carried out without regenerative practices, accumulates disturbances over time, putting millions of hectares under the possibility of a collapse via nutrient degradation and soil erosion. Mining agriculture is reducing soil, fauna and root diversity, causing replacement of native species by invasive species of invertebrates, fungi and other important biological components of the soil, homogenizing the agroecosystem, simplifying landscape structure and increasing the occurrence of bioinvasions (Binimelis *et al.* 2009; FAO 2011a). This means degradation in the quality of these lands that are on the producing end of biomass transfers globally.

Figure 3.7 Regions of greatest nitrogen use in the world (Source: adapted from Townsend and Howarth 2010)



North China Plain:

More vigorous application of fertilizer has produced stunning increases in maize and wheat production, but China now has the highest fertilizer inputs in the world.

Southern Brazil:

Rapid population growth and industrailization around Sao Paulo, poor civic sewage treatment and vibrant sugar cane production all contribute to this new South American nitrogen hotspot.

Shifting hotspots

Regions of greatest nitrogen use (red) were once limited mainly to Europe and North America. But as new economies develop and agricultural trends shift, patterns in the distribution of nitrogen are changing rapidly. Recent growth rates in nitrogen use are now much higher in Asia and in Latin America, whereas other regions -including much of Africa- suffer from fertilizer shortages.

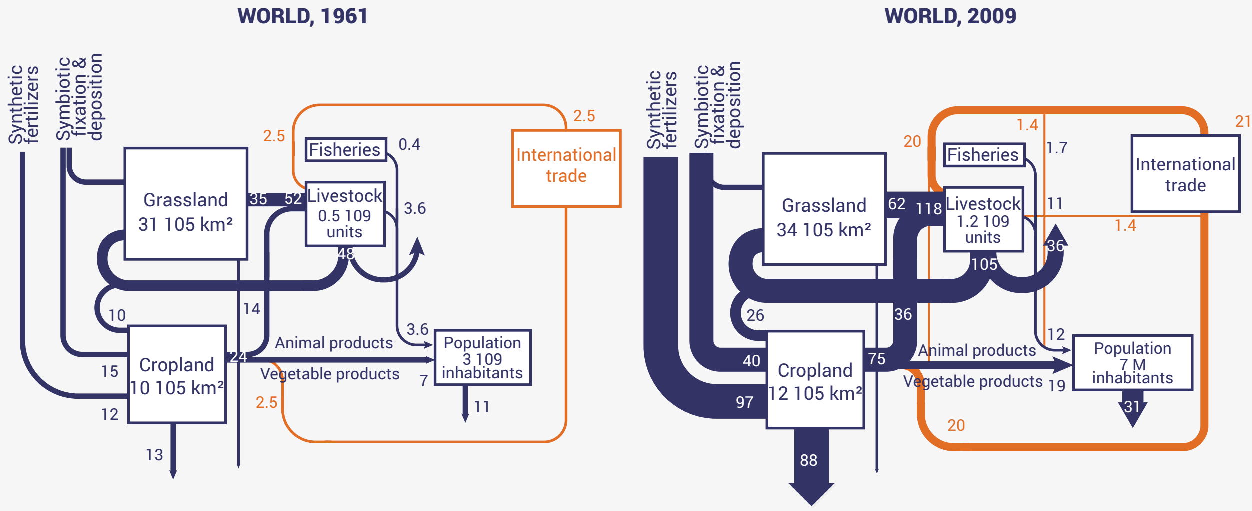
Changes in nutrient flows and concentrations: Changes in nutrient concentrations globally can also serve as an example of externalities and invisibles in global trade. Under the current agricultural and food trade at international level, the issue of nutrients flow is a relevant point, especially in terms of the environmental, agronomical and socioeconomic effects that the situation generates. While many modern agricultural activities - as well as traditional and mixed farming methods pushed to the limit by population and market pressure - are causing nutrient depletion, erosion and degradation in exporting territories (Styger *et al.* 2007; Tittonell and Giller 2013), in the importing territories of these grains, nutrient pollution is one of the main issues as a result of accumulation (Halberg *et al.* 2006).

Nutrient concentration in several regions of the world (see **Figure 3.7**) as a result of agriculture's increased biomass production and consumption is producing a nitrogen and phosphorous cascade with environmental and social impacts. As Townsend and Howarth (2010) indicate, the regions of greatest nitrogen use were once limited mainly to Europe and North America. However, as new economies develop, and agricultural trends shift, patterns in the distribution of nitrogen are changing rapidly. Recent growth rates in nitrogen use are now much higher in Asia and in Latin America, whereas other regions—including much of Africa—suffer from depletion of nutrients in soils.

Continual increases in beef production lead to surges in nutrients flow (Townsend and Howarth 2010; Chemnitz and Becheva 2014). The demand for grain for cattle feed, and thus the intensive production of corn and soy in the American Midwest along with Brazil, Paraguay and Argentina has far reaching impacts. Such high levels of production are often only made possible by a production system equally high in inputs. Yet the application of agricultural chemicals to annual row crops is extremely "leaky"; it is estimated that less than 15 per cent of phosphorous, and 40 per cent of the nitrogen applied to crops is actually absorbed by the plants; the rest remains either in soils or in waterways each year, contributing to the over 400 oceanic dead zones (Zielinski 2014). This dynamic is variable, depending on soil characteristics and other environmental conditions, but remains problematic in the regions of greatest animal feed production.

Invisible flows in nutrients are also due to disconnects in production systems, across borders and continents. The international trade of food and feed products has profoundly affected the flows of nitrogen in the form of vegetable or animal protein between continents over the last fifty years (see **Figure 3.8**). Generalized representation of N transfers through the world agro-food system in 1961 and 2009). The largest component of traded agricultural commodities is animal feed, which enters international trade primarily from countries producing feedstuffs to countries where the proportion of meat in the human diet is high or rapidly increasing (Kastner *et al.* 2012), and which have intensive animal production facilities. This disconnect between crop and livestock production between countries and usually continents results in the inability to close nutrient cycles, thus causing nitrogen surpluses and inefficient use of nitrogen (Billen *et al.* 2015, Lassaletta *et al.* 2016). The large N surpluses are lost to the environment via surface runoff, leaching to ground and surface water, and gaseous emission, all representing large costs to society (van Grinsven *et al.* 2013; Sobota *et al.* 2015).

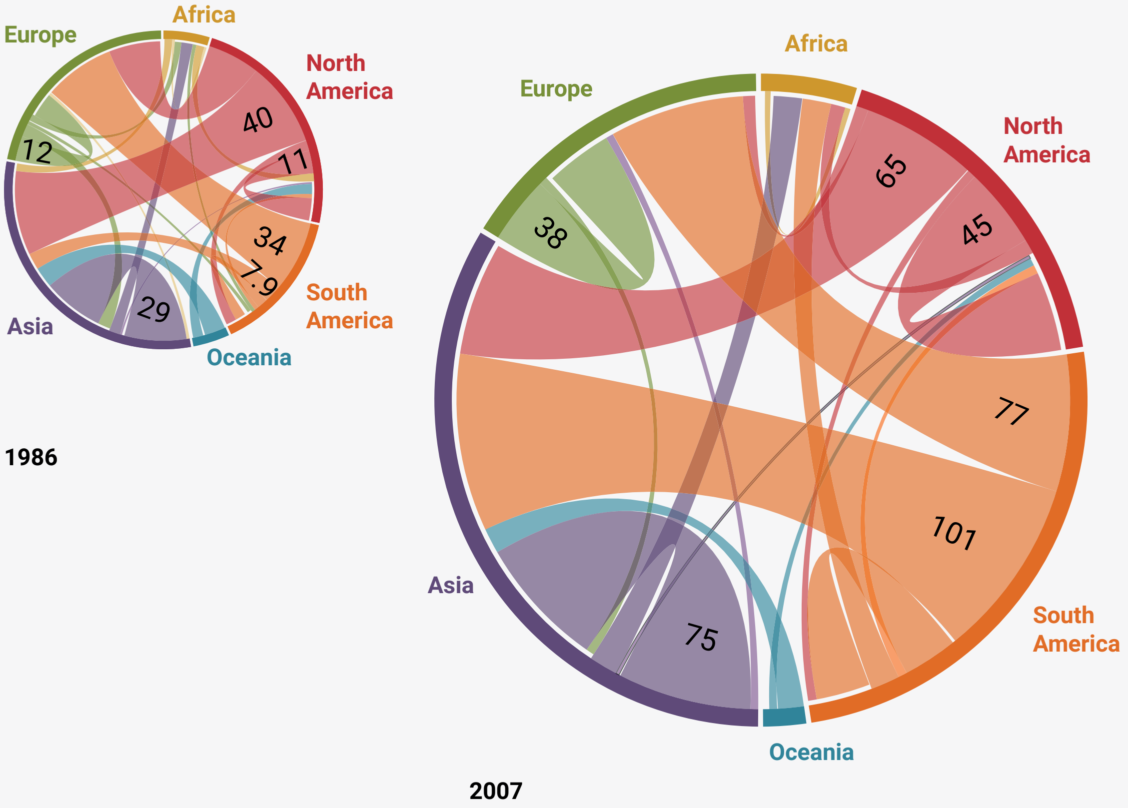
Figure 3.8 Generalized representation of Nitrogen transfers through the world agro-food system, 1961 and 2009 (Source: adapted from Lassaletta *et al.* 2016)



Teragrams Nitrogen (TgN) per year

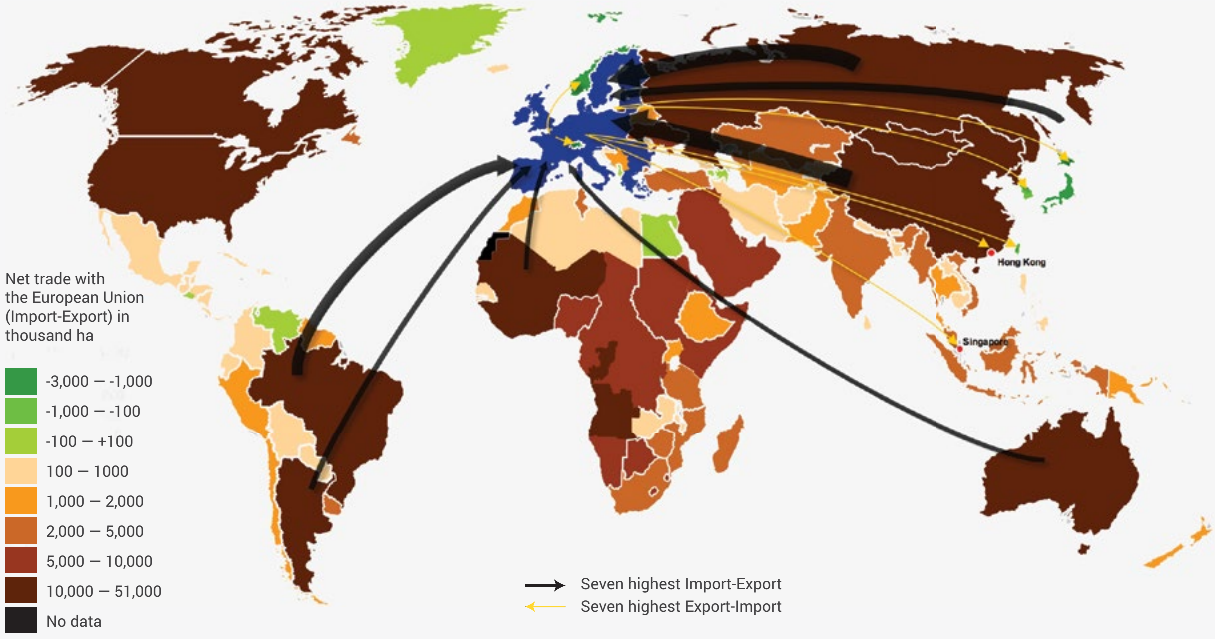
Virtual water: The concept of virtual or embedded water (Mekonnen and Hoekstra 2011) was first developed as a way to understand how water-scarce countries could provide food, clothing and other water intensive goods to their inhabitants. The global trade in goods has allowed countries with limited water resources to rely on the water resources in other countries to meet the needs of their inhabitants. As food and other products are traded internationally, their water footprint follows them in the form of virtual water. This allows us to link the water footprint of production to the water footprint of consumption in any location. The analysis of "virtual water flows" help us see how the water resources in one country are used to support consumption in another country. The largest virtual water exporters are in North and South America (Dalin *et al.* 2012). Virtual water flow between the six regions in Figure 3.9 remained somewhat similar in patterns between 1986 and 2007, but with large changes in volumes. South America, as can be seen, increased its participation in the international trade of virtual water, while Asia converted into one of the main importers (see **Figure 3.9**).

Figure 3.9 Virtual water flows between the six world regions (Source: adapted from Dalin *et al.* 2012)



Note: Numbers indicate the volume of virtual water flows (VWT) in km^3, and the colors of the links correspond to the exporting regions. The circles are scaled according to the total volume of VWT. Total VWT in 1986 was 259 km^3 versus 567 km^3 in 2007.

Figure 3.10 Trade balances of virtual land for the EU-27 (Source: adapted from UNEP 2015)



Virtual land: In the case of land, the terms of embodied land or intangible land are directly related to the ecological footprint concept (Costello *et al.* 2011; Steen-Olsen *et al.* 2012; Weinzettel *et al.* 2013; Yu *et al.* 2013). The concept recognizes that some agricultural and forest products – such as cattle, biofuels and forest products – are especially land-demanding. The consumption of these products remains high in certain regions, such as the US. Costello *et al.* (2011) concluded that the US was a net importer of embodied land, especially forest area. Similar studies exist for the European Union; these studies establish that the cropland demand in the EU linked to consumption in the region (estimated at .3 ha/cap) is larger than the EU's present cropland area (.25 ha/cap (Bringezu *et al.* 2012). Figure 3.10 presents the relationship between EU and the world in terms of virtual land imported (UNEP 2015).

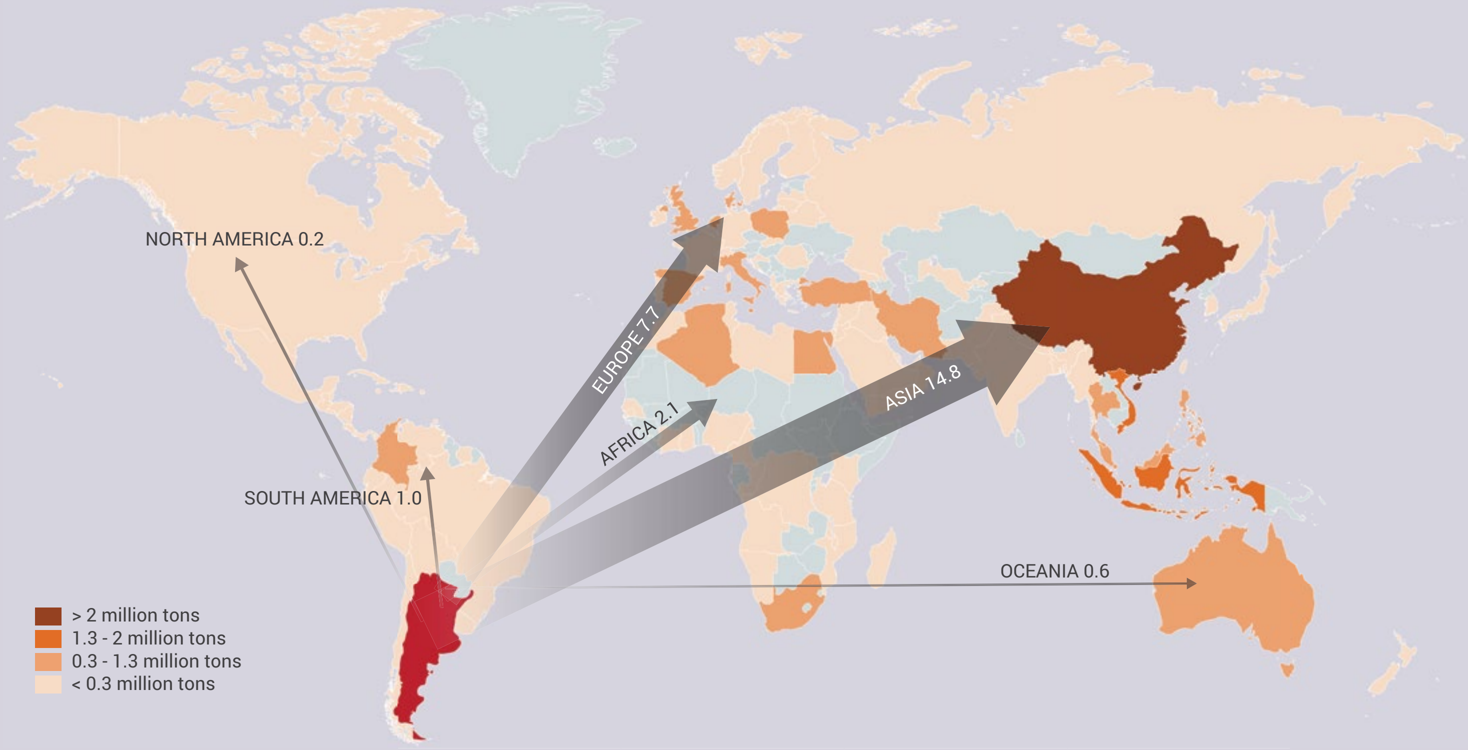
Virtual soils: Virtual soils (Pengue 2010; UNEP 2014) relate to the nutrient footprint in terms of intangibles that are incorporated in the grains, meat, wood, milk and other exports of biomass, and the export of nutrients extracted from the soils (see **Box 3.2**) where they are produced to the places where the grains and food are consumed. Using Denmark as an example, it was shown through a Life Cycle Analysis (see more on this method in Chapter 7) that the international flow of nutrients between producer and consumer countries (soybean in Latin America/pig production in Denmark) causes depletion of soils in the origin country and contamination in the reception country (Dalgaard *et al.* 2008). This has clear relevance for the ways in which the agriculture sector, in terms of nutrients, is contributing to exceeding planetary boundaries (**see Figure 3.4**).

Box 3.2 Soybean exportation and nutrient flows

Depletion of soils due to mining and industrial agricultural models is a key point of current ecological imbalances, with serious results for nutrient stability in the some of the world's best soils. The case of soybean and soil export in Argentina is illustrative (Altieri and Pengue 2006). Argentina has historically amassed and exported large amounts of nutrients for worldwide consumption, being a large food and biomass supplier to the world and relying on the high productivity of its fertile soils.

A continuous process of soil's nutrient depletion has been ongoing since 1961, as expressed by the last 55 years of nutrient extraction dynamics. The estimated nutrients harvested from 1961 to 2015 stood at 113Tg of nitrogen, phosphorus and potassium (NPK)(76 TgN, 11 TgP, 26 TgK), equal to an annual national average extraction of 64 kg N ha-1, 9 kg P ha-1 and 22 kg K ha-1 (Díaz de Astarloa and Pengue 2016). This soil exhaustion represents a 'hidden cost' or environmental intangible (Pengue 2009), since the export of nutrients from soils as natural capital remains unaccounted for. This ecological trade-off needs to be reconciled in order to minimize environmental impacts, avoid soil degradation and sustain the ability of the landscape to produce food. Argentina is seen as the "barn of the world", owing to its high quality soils, especially in the Pampas region, but it can also be portrayed as a main extractor of nutrients. The main consumers of these virtual soils are located in Asia (especially China), Europe and Africa (see **Figure 3.11**).

Figure 3.11 Nutrients exported in soybean products from Argentina, 2007-2017 (Source: adapted from Diaz de Astarloa and Pengue 2016)



3.3.4 Logistics and transportation costs in the food chain

Food travelled 50 per cent farther in the early 21st century to reach the UK and 25 per cent further to reach the USA compared to distances travelled in the 1980s (Halweil 2002). The increase in food transport distances and the reduction in maritime transport costs and logistical and port costs has not only negatively impacted the environment but also increased the risks related to food quality, biosafety, invasive species, and traceability.

Logistics refers to the movement (forward and reverse) and storage of goods (food, food-producing animals and other agricultural goods) and associated financial and information flows. Since logistics activities require extensive use of human and material resources that affect a national economy, developed countries like the UK and USA have devoted considerable attention to improving the technology and management of logistics activities and costs (Bosona 2013).

In developing countries, on the other hand, the available transport infrastructures are relatively poor and physical destruction of transported foodstuffs are common due to flooding, local and regional conflicts, and lack of appropriate storage facilities and maintenance. Inadequate logistics services are associated not only with food waste but also with food contamination and spread of disease at different stages of the food supply chain (Bosona 2013).

With respect to storage facilities, in many countries, especially poor countries, on-farm storage capacity is lacking. In addition the lack of equipment and infrastructure to transport the produce to processing plants or markets immediately after harvesting also contributes to food loss. In some cases, the available transport services may be interrupted due to damage on roads caused by flooding or armed conflicts leading to product loss due to spoilage, theft or total damage. For example, in Uganda, dairy farmers were forced to stop marketing their milk because of flooding in 2007 (Choudhary *et al.* 2011). In countries such as El Salvador or Ecuador, logistical and transportation costs rise as results of earthquakes. Inadequate logistics services are associated not only with food waste but also with food contamination and spread of disease at different stages of the food supply chain (Bosona 2013). Logistical risks in agriculture are broad and varied; this chapter section focuses on the major types.

Logistics-related food loss is high in low-income countries. Comparatively, food loss at the consumption level is higher in high-income countries. In Sub-Saharan Africa, around 8 per cent of cereal production, 15 per cent of dairy production, and more than 35 per cent of fruits and vegetable products are lost due to logistics-related problems (Gustavsson *et al.* 2011). Even in industrialized Asian countries (Japan, China and South Korea), around 15 per cent (142 million tons per year) of fruits and vegetables are lost due to logistics related problems. Punctures (due to inappropriate containers and packaging), impacts (due to bad roads and driving behaviour), compression (due to overfilling of containers and inappropriate loading), and vibration (due to rough roads and bad driving behaviour) as well as exposure to high or low temperature, moisture, chemical contaminants and insects are main causes of logistics-related damages to fruits and vegetable products.

According to information obtained from the FAO, global fish loss caused by spoilage is significant, totalling around 10-12 million tons per year (HLPE 2014). In Latin America, South and Southeast Asia, approximately 25 per cent of fish and seafood products are lost due to logistics-related problems, because high levels of deterioration occur during distribution of fresh fish and seafood (Gustavsson *et al.* 2011). Similarly, the logistics-related loss in dairy products is significant (more than 10 per cent) in developing countries. Inability to market milk products during rainy season, lack of properly refrigerated transportation, erratic power supply to milk processors and coolers are some of the causes of losses in dairy products (Gustavsson *et al.* 2011).

Logistics-related risks also occur in the transportation of food producing animals. Transport of livestock is known to be stressful and injurious, which leads to production loss and poor animal welfare. For example, in the USA, about 80,000 pigs die per year during the transportation process (Greger 2007). A case study in Ghana indicated that more than 16 per cent of expected income is lost due to occurrence of death and sickness or injuries of cattle during transport from farm to cattle market and abattoir (Frimpong *et al.* 2012). A similar case study in central Ethiopia (Bulitta *et al.* 2012) indicated that during cattle transport from farm to central market, over 45 per cent of animals were affected (either stolen, injured or killed).

3.3.5 Effects of socio-economic crises

The effects of volatile food prices along with financial and economic crises can impact the most vulnerable by lowering or disrupting real wages and impacting their major sources of income. High food prices threaten to reverse critical gains made towards reducing poverty and hunger (Weinberger *et al.* 2009). During the economic and financial crisis a decade ago (2008), FAO estimates that higher food prices meant that nearly 1 billion fell below the hunger threshold by the end of 2008 before improving slightly in 2010 to around 925 million (Thompson 2008).

Disasters destroy critical agricultural assets and infrastructure, and cause losses in the production of crops, livestock and fisheries. They can change agricultural trade flows, and cause losses in agricultural-dependent manufacturing sub-sectors such as textiles and food processing industries. Disasters can slow down economic growth in countries where the sector is important to the economy and where it makes a significant contribution to national Gross Domestic Product (GDP). Agriculture contributes as much as 30 per cent of national GDP in Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Ethiopia, Kenya, Mali, Mozambique, Nepal and Niger among others, as examples of countries where natural disasters have had massive impacts (FAO 2015b). Between 2003 and 2013, natural hazards and disasters in developing countries affected more than 1.9 billion people and caused over USD 494 billion in estimated damage (ibid.).

When disasters strike, they have a direct impact on the livelihoods and food security of millions of small farmers, pastoralists, fishers and forest-dependent communities in developing countries. Agriculture employs over 30 per cent of the labour force in countries such as Bolivia, Cambodia, Cameroon, Guatemala, India, Indonesia, Nicaragua, Niger, Philippines, Sri Lanka, and Viet Nam, and over 60 per cent of people in Burkina Faso, Ethiopia, Kenya, Madagascar, Mali, Tanzania, Uganda and Zambia.

In order to add an additional layer of analysis to the damage that disasters—including small-scale disasters—cause to crops and livestock, FAO used the DesInventar database, which reports damages to crops in hectares, and to livestock in units lost on the basis of 56 national databases. According to the data reported in DesInventar, 58 million hectares of crops were damaged, and 11 million livestock lost due to disasters occurring between 2003 and 2013. FAO used the same data, and the formula applied in the United Nations International Strategy for Disaster Reduction Global Assessment Report 2013 to calculate the monetary value of this physical damage, at approximately USD 11 billion. This figure is comparable with the results from post-disaster needs assessments, which covered medium- and large-scale events in 48 countries, indicating a total damage to crops and livestock of around USD 7 billion (FAO 2015b). Both DesInventar data and the post-disaster needs assessments analysis represent an underestimate of the overall damage caused by natural hazards and disasters to agriculture since they cover only 48 to 56 countries.

Over the past 30 years, the typology of crises has gradually evolved from catastrophic, short-term, acute and highly visible events to structural, long-term and protracted situations resulting from a combination of multiple contributing factors, especially natural disasters and conflicts. Climate change, financial and price crises are increasingly common exacerbating factors. In other words, protracted crises have become the new norm, while acute short-term crises are now the exception. Indeed, more crises are considered protracted today than in the past (FAO 2015b; HLEF 2012). In this respect, it should be noted that changes related to climate change (such increase in temperature, shift in precipitation) are slow, and in many places they have not yet been perceived as a crisis, yet they may already affect availability and accessibility of food.

From a food security and nutrition perspective, in 1990, only 12 countries in Africa were facing food crises, of which only four were in protracted crisis. Just 20 years later, 24 countries were facing food crises, with 19 of these having been in crisis for eight or more of the previous 10 years (FAO 2015b). In 2016 the number of chronically undernourished people in the world is estimated to have increased to 815 million, up from 777 million in 2015 although still down from about 900 million in 2000 (FAO 2017a). Moreover, the growing imperative of dealing with the long-term contexts of these emergencies is becoming evident. For instance, the Bosphorus Compact reported that global humanitarian appeals between 2004 and 2013 increased by 446 per cent overall – rising from US$3 billion to US$16.4 billion (FAO 2015b). Similarly, the number of displaced people at the end of 2013 was 51.2 million, more than at any point since the end of World War II (FAO 2015b). The average length of displacement in major refugee situations is now 20 years. Over the past three decades, humanitarian crises have grown in complexity and length. Nine out of ten humanitarian appeals continue for more than three years, with 78 per cent of the spending by the Organisation for Economic Cooperation and Development (OECD)'s Assistance Committee donations allocated to protracted emergencies. Human-induced conflicts are increasingly the main underlying cause for food crises, often related to or being amplified by natural disasters (FAO 2015b).

The complex relation between conflict and food security and nutrition is yet to be fully explored, but the capacity for conflict to accelerate food insecurity and famine is evident in many recent events. Food insecurity can be a direct result of violent conflict and political instability as well as an exacerbating factor. On the one hand, food insecurity is a factor that can trigger and/or deepen conflict, often due to underlying economic and structural factors. For instance, sudden and unforeseen food price rises, or the reduction or removal of subsidies on basic foodstuffs, can be a catalyst for civil and political unrest, as in the social upheaval and political violence of the Arab Spring in 2011 when governments in the Near East reduced subsidies for bread (FAO 2015b). Natural disasters, drought and famine can also contribute to political unrest and violent conflict, as evidenced by the Sahel and West Africa region. Food insecurity can exacerbate political instability and violent conflict when specific groups are economically marginalized, services are distributed inequitably or where there is competition over scarce natural resources needed for food security.

Periodic conflicts between farmers and herders in the semi-arid Sahel and East Africa regions illustrate this.

In the worst of cases, widespread famine may result. All situations of extreme food insecurity and famine in the Horn of Africa since the 1980s have been characterized by conflict in some form, transforming food security crises into devastating famines. Globally, between 2004 and 2009, around 55,000 people lost their lives each year as a direct result of conflict or terrorism. In contrast, famine caused by conflict and drought resulted in the deaths of more than 250,000 people in Somalia alone between 2010 and 2012 (FAO 2015b).

3.3.6 Poverty and food security in relation to multiple forms of crises

Economic crises - including those that are generated by climate, weather and land/water resource degradation leading to the loss of crops, displacement and migration - generally produce massive disruption to food systems, both at the supply and demand end. The changing agricultural scenario caused by these crises often results in a vicious cycle involving the inability of farmers to make meaningful investments or get adequate returns from their resources. This cycle, which starts with broader economic crises, has its initial impacts at the farm level, and can then spread in many places to the larger local community and to regional levels.

Economic crisis and natural disasters make the poor even poorer: The decline in GDP due to large-scale disasters, which increase the depth and extent of poverty especially in affected developing countries, is often accompanied with loss of employment and income opportunities in the affected sectors. The need to replace damaged infrastructure also means that governments have to divert resources from long-term development objectives, compromising efforts to reduce poverty and food security.

When emergencies occur, households often resort to selling their assets, such as livestock and other holdings, to meet their emergency food needs. In extreme circumstances, people migrate in search of relief and employment. Poor households that incur injury and disability are hit harder, affecting their ability to work. The disruption of livelihood systems, with severe and repeated crop failure, results in further pauperization of households and communities.

The developing world has made substantial progress in reducing hunger since 2000. The 2016 Global Hunger Index (GHI) shows that the level of hunger in developing countries as a group has fallen by 29 per cent (IFPRI 2016). Yet this progress has been uneven, and great disparities in hunger continue to exist at the regional, national, and subnational levels. To achieve Sustainable Development Goal 2 (SDG2) of getting to Zero Hunger while leaving no one behind, it is essential to identify the regions, countries, and populations that are most vulnerable to hunger and undernutrition so progress can be accelerated there (IFPRI 2016).

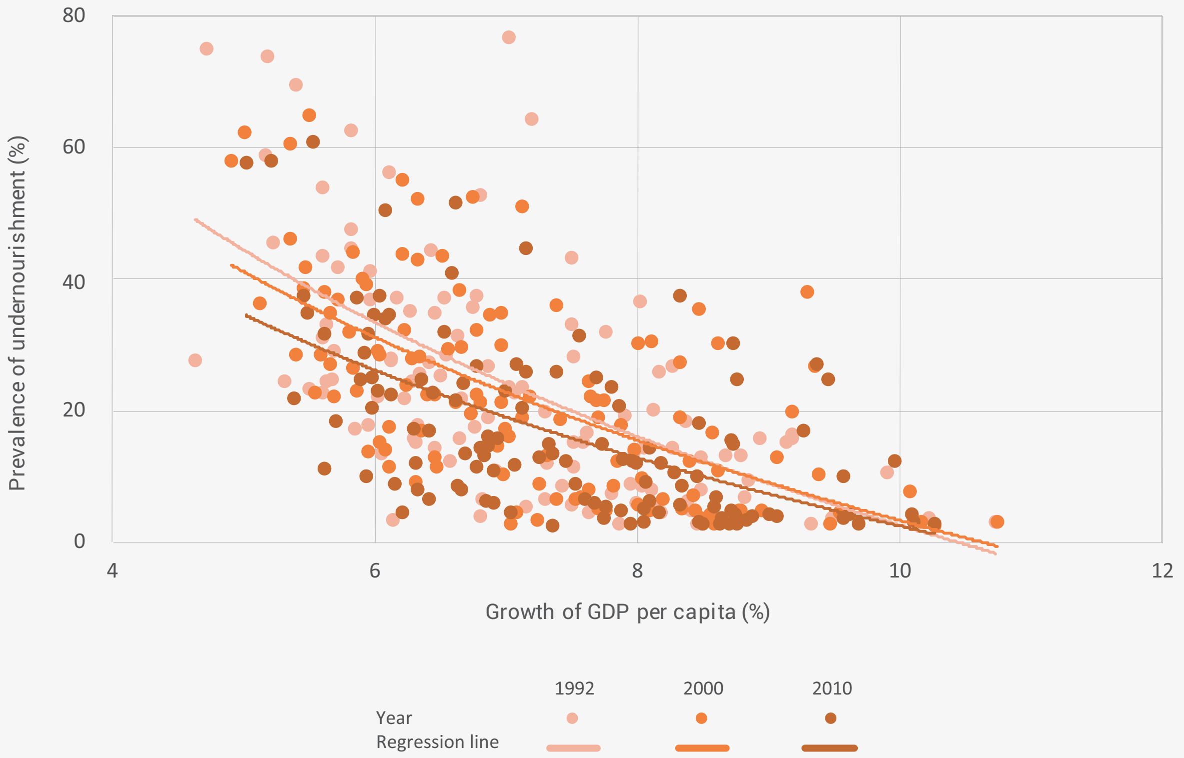
About 795 million people are undernourished globally, down 167 million over the last decade, and 216 million less than in 1990–92. The decline is more pronounced in developing regions, despite significant population growth. In recent years, progress has been hindered by slower and less inclusive economic growth as well as political instability in some developing regions, such as Central Africa and western Asia (FAO 2015a). In Africa the absolute number of hungry people has trended upward since 1996, even if the prevalence of undernourishment has gone down.

Economic growth and hunger: There are multiple complexities involved in the relationship between economic growth and hunger involving many political and governance aspects, although in general, undernourishment declines with increased growth (see **Figure 3.12**).

Economic growth and prevalence of undernourishment: Stunting and malnutrition of children has a very negative effect on the economic prospects of a population. While the overall trends are consistent, there are undercurrents and drivers in such trends that impact poverty and hunger. Economic growth increases household incomes through higher wages, increased employment opportunities, or both, due to stronger demand for labour. In a growing economy, more household members are able to find work and earn incomes. This is essential for improving food security and nutrition and contributes to a virtuous circle as better nutrition strengthens human capacities and productivity, thus leading to better economic performance. However, the question here is whether or not those people who are living in extreme poverty and are most affected by hunger will be given the opportunity to participate in the benefits of growth and, if they are, whether they will be able to take advantage of it. Governmental and political concerns also directly impact whether people are able to engage in economic activities.

In several cases, the positive effects of economic growth on food security and nutrition are related to greater participation of women in the labour force. In Brazil, for example, labour force participation of women rose from 45 per cent in 1990–94 to 60 per cent in 2013. In Costa Rica, the proportion of women workers increased by 23 per cent between 2000 and 2008. Spending by women typically involves more household investments in food and nutrition, but also in health, sanitation and education, compared to the case when men control resources (FAO 2015a). As documented by Smith and Haddad (2015) sanitation and female education are the largest factors related to reductions in child malnutrition, before levels of calorie production.

Figure 3.12 Economic growth and prevalence of undernourishment, 1992, 2000 and 2010 (Source: adapted from FAO 2015a)



3.3.7 Migration

According to the UN, "Migration is the movement of people, either within a country or across international borders. It includes all kinds of movements, irrespective of the drivers, duration and voluntary/involuntary nature. It encompasses economic migrants, distress migrants, internally displaced persons (IDPs,) refugees and asylum seekers, returnees and people moving for other purposes, including for education and family reunification" (FAO 2016a).

In 2015, there were 244 million international migrants, representing an increase of 40 per cent since 2000. They included 150 million migrant workers. About one-third of all international migrants are aged 15–34. Women account for almost half of all international migrants. A large share of migrants originates from rural areas. Around 40 per cent of international remittances are sent to rural areas, reflecting the rural origins of a large share of migrants. International remittances are estimated at three times the size of official development assistance. Internal migration is an even larger phenomenon, with 763 million internal migrants according to 2013 estimates. Internal and international migrations are often interconnected. In 2015, 65.3 million people around the world were forcibly displaced by conflict and persecution, including over 21 million refugees, 3 million asylum-seekers and over 40 million internally displaced persons (IDPs). A quarter of global refugees reside in only three countries (Turkey, Pakistan and Lebanon) (FAO 2016a).

The picture of dietary change in the face of such high levels of internal and international migration is complex, depending on a variety of factors related to country of origin, urban/rural residence, socio-economic and cultural factors and situations in host countries. The main dietary trends after migration are a substantial increase in energy and fat intake, a reduction in carbohydrates and a switch from whole grains and pulses to more refined sources of carbohydrates, resulting in a low intake of fibre. The data also indicate an increase in intake of meat and dairy foods. Some groups have also reduced their vegetable intake (Holmboe-Ottesen and Wandel 2012).

3.3.8 Biodiversity

Agriculture and its impacts on biodiversity are one of the major challenges to global sustainability. Food systems and the world's biodiversity interact in multiple dimensions. Agricultural biodiversity – from seeds to soil organisms to pollinators – underpin agricultural production and have an inestimable utilitarian value to human societies. In their own right, wild species of animals, plants and other organisms have intrinsic value. Yet current food systems – certainly modern and some mixed systems – pose the greatest threat to terrestrial wild species on Earth. It is crucial to consider not only the impacts of farming practices for on-farm biodiversity, but for off-farm biodiversity as well (through pollution, agricultural expansion and deforestation, fires, etc.), and in this respect different food and farming systems and their associated trade patterns have varied impacts on biodiversity Similar to the discussion of "virtual flows" of land and soil, virtual flows of biodiversity occur through such trade and associated supply chains. Developing country such as Indonesia, Madagascar and Papua New Guinea are losing biodiversity at high rates while developed countries such as the US, EU and Japan import large quantities of the commodities implicated in major biodiversity losses (Lenzen *et al.* 2012).

3.3.9 Food production, food scarcities, food access and governance in a complex world

The world food crisis (2007-2008), stemming from spiralling perceptions and concerns over of high oil prices, climate change, financial and banks meltdowns, and the consequent political reactions, has raised awareness about the lack of appropriate food system governance and pointing to the need for profound changes in the food system. On the supply side, the growing competition for land, energy and water leads to resource depletion, under current conventional practices. The paradigm of "structural transformation" that shaped economic thought and development theory for many decades envisioned a future of agriculture with industrial styles of production, with fewer farmers feeding growing urban populations (Herrendorf *et al.* 2014). Many questions remain on this envisioned future, amongst which are the realities of large rural populations likely to persist in India and sub Saharan Africa (Dorin 2017).

On the demand side, the world's population continues to increase, albeit at diminishing rates. Urbanisation of the world already transformed the ways food is produced, purchased and marketed (UNEP 2014). In many countries with growing economies, people would like to eat a richer diet that demands more resources to produce, yet there is at present no governance system that can help make the larger societal decisions that could guide diet changes while not incurring further environmental, social and health costs. The dearth of laws and legal institutions that could mitigate the dangers of inequality and promote greater fairness in food governance (Kennedy and Liljeblad 2016) is a major roadblock to ensuring rational, informed decision making and governance over food systems on many levels.

3.4 PATHWAYS TO SUSTAINABILITY FOR AGRICULTURE AND FOOD SYSTEMS

In this chapter so far, global external forces and economic pressures on the food system have been reviewed, and the resulting invisible flows of resources as a result of these forces and pressures were examined. Further evidence of a system that is cracking under pressure can be seen in the linkages between conflict, famine, migration, poverty and malnutrition, and the failures of governance. In this section, we intend to look for the pathways to reverse these trends. In important respects, the findings outlined above also hold the keys to understanding how we can pursue greater sustainability in the food system and more stable and resilient production of agricultural products.

3.4.1 The interdependence of nature and agriculture

Agricultural systems are part of the geological, biological and social processes that occur in the biosphere, so their evaluation must consider these interdependencies. Humanity has been farming for at least 10,000 years. For most of that time, agriculture has been small-scale, labour-intensive, and dependent on making use of, and modifying, natural processes to support food production. In understanding TEEBAgriFood, we recognize that there has existed a rich heritage and knowledge base in using nature to underpin agriculture. As detailed in earlier sections of this chapter, however, the last half century or more has witnessed a rapid revolution in the technology of agricultural production, particularly in the developed world, that has allowed the widespread adoption of industrial-scale farming techniques. By its very nature, modern agriculture to a large extent involves breaking such dependencies, managing land in ways that conflict with the conservation of biodiversity and the healthy functioning of ecosystems. Pathways to sustainability, going forward, must entail recognizing and strengthening those forms of agricultural production that explicitly enhance those ecosystem services and build the natural capital that underpin food systems, creating regenerative forms of agriculture and food that generate multiple positive externalities. In each of the subsections below, we first delineate the nature of these interdependencies and how they have been disregarded by modern conventional agriculture, before exploring how they may be restored.

Biogeochemical flows: Biogeochemical flows, coupled with changes in terrestrial ecosystems, are one of the key aspects of the global system models used within the

United Nations Framework Convention on Climate Change to understand interactions between human activity and the world's climate systems (Prinn 2013).

While the use of nitrogen in agriculture is estimated to have increased 8-fold over the period of 1960 to 2000, many studies also reveal extremely low N use efficiency (Fixen and West 2002; Liu *et al.* 2010), resulting in the global nitrogen flows noted in earlier sections. However, there are many ecosystem-based measures that can reduce this "leakiness". Many begin with finding other sources of nitrogen other than the extremely labile nitrogen in conventional fertilizers, drawing on the ecological process of nitrogen fixation through crop rotation and cover crops. These, along with measures to facilitate the ecosystem service of nutrient cycling through applications of compost and organic manure, enhance the capacity of soils to hold and supply plant nutrients, and improve nitrogen capture by crops.

Such practices are of great importance in tropical areas where traditionally, farmers have fallowed portions of their land to restore soil fertility through natural processes. But farming plots have diminished in size, customary fallow periods have been reduced to essentially zero in many localities. Without other measures to sustain soil healthy and fertility, organic matter of soils is being reduced and crop yields inevitably follow. Thus, replacing fallowing with other soil fertility ecosystem services is critical (Bunch 2016).

Measures on a landscape level can recapture lost nitrogen from fields by applying watershed-level strategies, such as encouraging diversity in agricultural landscapes, including hedgerows, vegetated strips and riparian habitat (Robertson and Vitousek 2009). Analyses of whole food systems have shown considerable opportunities to reduce nitrogen contamination of ecosystems while sustaining food productivity (Smil 2002), including modifying trade patterns to become more localized (Billen *et al.* 2014).

Equally, the current agricultural use of phosphorus in fertilizers have profoundly altered global phosphorous cycles, such that it is thought to be accelerated two to three time over background rates (Smil 2002), leading to widespread eutrophication of the world's freshwater and estuarine systems (Bennet *et al.* 2001; Conley *et al.* 2002) and negative impacts on biodiversity (Wassen *et al.* 2005). Access to a limited resource such as phosphorus is as much an economic issue as a natural resource issue, in particular for smallholder farmers in different parts of the world. Its sustainable and equitable use needs to be addressed in an appropriate transdisciplinary manner (Scholz *et al.* 2013). As with nitrogen, the focus of mitigation is first to reduce introducing additional phosphorous to systems through building soil health. A second key approach is to increase the use of recycled phosphorus, to the extent possible, from manure, human excreta and food residues (Elser and Bennet 2011). In addition, watershed-level measures to establish and maintain riparian buffers and restore wetlands are being called upon to reduce phosphorous loss to aquatic systems (Cordell and White 2013).

All of these measures seek to draw biogeochemical flows into tighter cohesion, reducing inputs and deleterious outflows, while building the natural capital and capacity of agricultural ecosystems to generate and retain its sources of growth and fertility.

Control of pests and diseases: Pest and diseases of crops and livestock have consistently been some of the most challenging problems facing farmers throughout history. It is increasingly recognized that the approach that industrialized, modern agriculture has taken to controlling pests – through application of pesticides in sprays or seed treatments generates far more problems than it solves. Global pesticide use has grown over the past 20 years to 3.5 billion kg/year, amounting to a global market worth $45 billion (Pretty and Bharucha 2015). Pesticide and herbicide resistance continues to grow even as the toxicity of pesticides increases (Cresswell 2016). In a recent review of the global impact of agricultural insecticides on freshwater, it was reported that the concentration of 50 per cent of the insecticides detected in freshwater exceeded regulatory thresholds for environmental and human health (Stehle and Schulz 2015). Losses to pests and disease are estimated at 20-40 per cent of global crop yields (FAO 2015c), indicating this is not a battle that is being won by conventional crop protection. Secondary pest outbreaks and growing resistance on the part of pests - both plant and animal – are key problems for modern agriculture (Hill *et al.* 2017). Reports of insect pest problems and crop losses indicate increasing trends of pest outbreaks for a number of commodity crops such as cotton, sugarcane and tobacco (Dhaliwal *et al.* 2010). Estimates of the externalities of pesticides are from $4–$19 per kg of active ingredient applied, suggesting that efforts to reduce pesticides will benefit a wide group of stakeholders from farmers to consumers and those concerned with health (Pretty and Bharucha 2015).

Thus the science of pest and disease control is increasingly returning to its original roots: recognizing first that not all insects or microorganisms are pest or disease agents, and that there is almost always as subcritical level of both herbivores and pathogens in agroecosystems. Ecological approaches work to restore those balances when they become critical, through a host of careful monitoring, use of cultural techniques and on-farm diversity, choice of appropriate varieties and introduction of natural enemies. For example, and as profiled in the rice case study in Chapter 8, rice production systems managed with ecological approaches are capable of generating multiple ecosystem services, including sustaining natural pest control and inherent fertility. This approach is undermined by the use of agrochemicals, leading to severe pest outbreaks (Thoburn 2015; Settle *et al.* 1996). Building natural capital in agroecosystems is an investment over time, to create an environment favourable to natural enemies and other beneficial insects.

The UN Convention on Biological Diversity (CBD), with a focus at its 13th Conference of Parties on mainstreaming biodiversity into the agriculture, fisheries and forestry sectors, has presented case studies (together with FAO) of the contribution of biodiversity-mediated ecosystem services such as pest and disease control to agricultural production in East Africa and the Pacific Region (FAO and CBD 2016a; 2016b).

Pollination: Pollination as a factor in food production and security has been little understood and appreciated by conventional agronomy, in part because it has been provided by nature at no explicit cost to human communities. However, over the last two decades, there is a deeper understanding that the pollination contributes to the yields of at 35 per cent of all crops (Klein *et al.* 2007), particularly those that provide critical vitamins and other nutrients (Smith *et al.* 2015). At the same time, as farm fields have become larger, and the use of agricultural chemicals that impact beneficial insects such as pollinators along with plant pests has increased, pollination services are showing declining trends. The domesticated honeybee (and its several Asian relatives) have been utilized to provide managed pollination systems, but for many crops, honeybees are suboptimal pollinators compared to wild species. Thus, the process of securing effective pollinators to "service" large agricultural fields is proving difficult to engineer, and there is a renewed interest in helping nature provide pollination services. A recent global meta-analysis provides insight into how this ecosystem service can best be secured (Garibaldi *et al.* 2016). Smallholder farmers, cultivating fields of less than two hectares, can effectively increase yield gaps by a median of 24 per cent by promoting greater visitation of pollinators to their crops; their already high levels of diversity support populations of pollinators that can be enhanced by relatively simple measures. For larger, more intensive forms of cultivation, similar benefits can be found, but only by very focused measures to increase the diversity and richness of pollinators (of which, reducing the use pesticides is an important one).

For this ecosystem service as for others, there can be synchronous benefits for biodiversity and for agriculture (Gemmill-Herren 2016; IPBES 2016). The CBD has recognized the contribution of pollination to human welfare, through the establishment (and recent renewal) of the International Initiative on the Conservation and Sustainable Use of Pollinators[3]. The first thematic assessment carried out by the IPBES was on pollinators, pollination and food production, thoroughly documenting the role and value of both wild and managed pollinators to global food production (IPBES 2016).

Freshwater use: There remains uncertainty over the extent to which freshwater planetary boundaries are being exceeded by agriculture's use of water (Campbell *et al.* 2017). In certain regions conventional water impoundment, groundwater pumping and irrigation schemes for agriculture around the world have had serious impacts on water quality and quantity for communities and for nature. If watershed services (understood as water purification, ground water and surface flow regulation, erosion control, and streambank stabilization) are appreciated as being the context within which water is locally provisioned, ways of managing freshwater use can be seen as integral to ecological approaches in agriculture.

The fundamental role of freshwater in support of the environment, society and the economy, and its interactions with farming activities is recognized directly by at least two Sustainable Development Goals (2 and 14) and UNEP's Freshwater Strategy 2017-2021 (UNEP 2017); in fact, freshwater is implicated in all sustainable development goals.

Seeds and genetic diversity: The diversity of species contributing to agricultural production has seen a dramatic narrowing over recent decades, as a few major energy-dense cereals (maize, wheat and rice) and major oil crops have come to dominate both production and global diets. (Khoury *et al.* 2014), accompanied by declines in consumption of pulses (Akibode and Meredia 2011) and underutilized crops (Padulosi *et al.* 2002). Food supplies worldwide have become more homogenous and composed of processed food products, to the detriment of local, often better adapted and more nutritious food crops such as other cereals, root crops and diverse beans (Khoury *et al.* 2014). Yet genetic diversity, as manifested in seeds and livestock breeds, is greatly appreciated as an ecosystem service that is essential to sustainable agriculture (Haijer *et al.* 2008). Even within any of the major crops, the attributes of diverse seeds remain of great value, contributing to multiple ecosystem services and resilience. The example of rice featured in a TEEBAgriFood feeder study (Bogdanski *et al.* 2017), noted that with its long history of cultivation and selection under diverse environments, rice has acquired a wide adaptability, enabling it to grow in a range of environments, from deep water to swamps, irrigated and wetland conditions, as well as on dry hill slopes. The quality preferences of rice consumers, over millennia, have resulted in a wide diversity of varieties specific to different localities. There are estimated to be

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[3] See, for example, document CBD/SBSTTA 22/10.

around 140,000 different genotypes among thousands of different rice varieties, some of which have been around for centuries while others are new hybrids bred to increase rice yields or reduce the susceptibility to rice pests. While the governance over genetic resources remains a contested space, many believe that legal frameworks should support a pluralistic variety of seed supply and encourage exchange with farmers served by a number of institutions, including – but not limited to – those in the private sector and intergovernmental bodies, including the CBD, the Commission on Genetic Resources for Food and Agriculture, and the International Treaty for Plant Genetic Resources. Many other actors focus on civil-society mechanisms to ensure resilient and diverse seed systems. Such systems have values in many dimensions, beyond economics, including cultural diversity, culinary traditions, health and wellness, and resilience (Global Alliance for the Future of Food 2018).

Cultural diversity: Ecosystem services are not purely bio-physical in nature. Cultural diversity and traditional and local knowledge should also be respected as an ecosystem service that merits greater appreciation. Farmers' knowledge and understanding of management of local natural resources and knowledge of local cultural and social systems are a key foundation for building resilient eco-agri-food systems. The value of the context-specific and continuously adapted knowledge of farmers to find solutions for complex and dynamic ecological and human systems is inestimable. Increasingly, it is being recognized that co-creating knowledge between farming communities and scientists, and the many mediating organizations in between, including farmer organizations, non-governmental organizations, governmental extension agencies and community-based organizations can lead to designing adaptive food systems that effectively address food and nutrition security (ILEIA 2016).

Mechanisms to highlight cultural diversity, local traditions and farmer knowledge have been found, for example, in the recognition of agricultural heritage systems. The existence of numerous globally important agricultural heritage systems (Koohafkan and Altieri 2011) around the world testify to the inventiveness and ingenuity of people in their use and management of finite resources, biodiversity and ecosystem dynamics, and ingenious use of physical attributes of the landscape, codified in traditional but evolving knowledge, practices and technologies. The values of heritage systems reside in the fact that they offer outstanding aesthetic beauty, are key to the maintenance of globally significant agricultural biodiversity, and include resilient ecosystems that harbour valuable cultural inheritance, and also have sustainably provisioned multiple goods and services, food and livelihood security for millions of poor and small farmers, local community members and indigenous peoples.

A number of international processes are calling for the development of indicators that reflect the value of the ecosystem services and processes as described here, contributing to agriculture and sustainable development. Among these are the 2030 Agenda for Sustainable Development and the SDGs, the UN Framework Convention on Climate Change, the UN Convention on Biodiversity and the Aichi biodiversity targets and the UN's Global Strategy to Improve Agricultural and Rural Statistics, including the System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries (SEEA AFF) (FAO 2018). To take just one of these, the TEEB secretariat has mapped, as an example, the value generation from ecosystem services in Asian rice production systems to virtually all of the Sustainable Development Goals (see **Figure 3.13**).

Figure 3.13 Mapping of value generation in smallholder Asian rice production systems to the Sustainable Development Goals (Source: authors; Image source: Wikimedia)

SDG 13 - Climate regulation
Micro, regional and global climate regulation are influenced by greenhouse gas concentrations due to land use change (eg. deforestation). Alternative wetting and drying of rice fields can reduce methane emissions by 45 percent.

SDG 2,4,6,13 - Freshwater
(Hydrological cycle and water flow maintenance)
Based on indigenous knowledge, the communally-managed forestry areas and upstream terraces serve as a rainwater retention and filtration system.

SDG 1,8.5,9.3 - Employment and income
Labour intensive rice farming in Asia *provides livelihoods* to around 140 million rice farming households.

SDG 11.4, 4.7, 12.8 - Cultural heritage
Physical, intellectual, symbolic and other interactions arise in rice production landscapes; Social cohesion is built around *indigenous agricultural innovations*, communal decision-making and respecting local customs.

SDG 15 - Habitat for species
Habitat for species for birds and vertebrate wildlife.

SDG 1, 2, 3 - Food
Nutritional value for rice farming households and landless members of the community. Combined rice-and-fish farming provides *nutritional diversity* from aquatic habitat.

SDG 2.5, 3 - Genetic diversity
Exchange of seeds with neighboring farms to avoid pest problems.

SDG 15 - Erosion control
Vegetation cover and terrace structure protect/stabilise terrestrial ecosystems (erosion landslide, gravity flow protection.

SDG 3, 12.4, 15 - Pest and disease control
Eliminate negative health externalities** from fertilisers and pesticide use through natural pest control and integrated pest management.

1: End poverty in all its forms everywhere
2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture
2.4: Sustainable food production systems and resilient agricultural practices
2.5: Maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species
3: Ensure healthy lives and promote well-being for all at all ages
4.7: All learners acquire the skills needed to promote sustainable development, including, sustainable lifestyles and appreciation of cultural diversity to sustainable development
6: Ensure access to water and sanitation for all
8.5: Achieve full and productive employment and decent work for all women and men
9.3: Access of small-scale industrial and other enterprises, in particular in developing countries, to financial services, including affordable credit, and their integration into value chains and markets
11.4: Strengthen efforts to protect and safeguard the world's cultural and natural heritage
12.4: Achieve the environmentally sound management of chemicals and all wastes throughout their life cycle
12.8: People have the relevant information and awareness for lifestyles in harmony with nature
13: Take urgent action to combat climate change and its impacts
15: Protect restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land degradation, halt biodiversity loss

* Ecosystem service mapping based on CICES classification

** Health externalities from fertilizers and pesticide use, such as emissions from pesticide production, farmer health risk from chemicals handing in fertilizer and pesticide manufacture; farm worker health costs from exposure to pesticides, weedicides, fertilizers and unmanaged waste, food consumption human health costs

3.4.2 Ecological management across landscapes

Farms are inherently embedded in natural and human systems. To apply ecological approaches, there is a need to work across and within landscapes, communities and territories. Certainly, managing freshwater resources occurs at a landscape or territorial scale, as does building appreciation for cultural diversity. Biodiversity conservation efforts are also best coordinated at these larger scales. Measures to use biodiversity to filter waterways and retain nutrients require landscape interventions. Farmer exchanges of seeds and other genetic resources occur within and between communities. Ecosystem services such as pollination and natural pest control stand to benefit tremendously from temporal, spatial, and genetic diversity resulting from farm-to-farm variations in cropping systems.

FAO and other actors have articulated landscape approaches to sustainable agriculture. (FAO 2017c; Tscharntke *et al.* 2005). Such approaches are designed to deal, in an integrated and multidisciplinary manner, with the multi-functional roles of production landscapes, bringing in environmental and social considerations to address underlying causes of degradation and food insecurity. Human activities and institutions are viewed as integral to agricultural systems, and multi-stakeholder involvement is often central to resolving management issues. Some examples of landscape approaches to sustainable agriculture include forest restoration and sustainable forest management to support watershed services for farmers as well as forest dwellers, and integration of fishery practices in irrigation and other water systems. Effectively and equitably integrating the benefits of multiple ecosystem services in land management and planning demands levels of ecological literacy, understanding of socio-economic conditions, and local governance systems at a landscape scale rather than at a local farm scale (FAO 2017c).

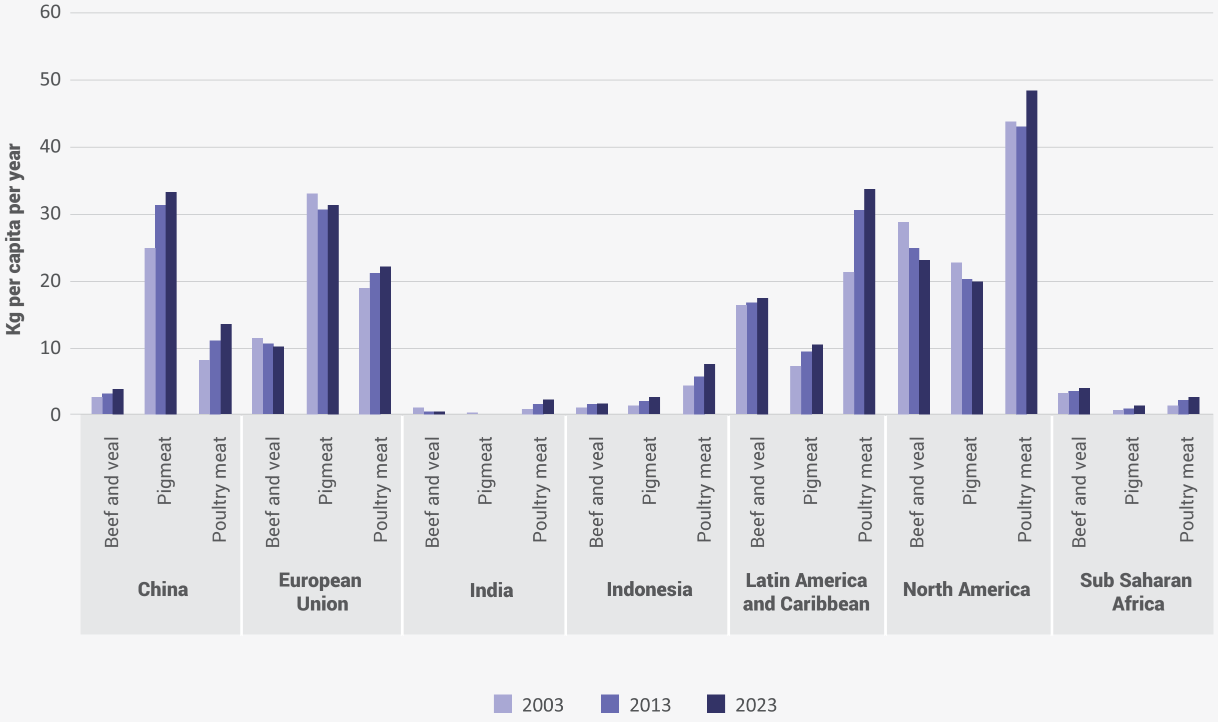
3.4.3 Environmental implications of changing diets: options and alternatives

As noted previously, broad patterns in diets are changing globally in fairly consistent ways, linked to increases in income and urbanization over the last half-century. Rising demands – in the sense of quantities food brought into a household - can be seen for meat, "empty calories" derived from refined sugars and fats, and total calories per person (Tilman and Clark 2014). Asian diets are in striking transition, led by China because of urban migration, a growing middle-class and rising incomes (see **Figure 3.14**). This global dietary transition- and its future trajectories- is one of the greatest challenges facing the world. While the impacts of changing diets on human health and nutrition are addressed in more depth in Chapter 4, in this section we present some of the current understanding of different, and changing, diets on the environment.

Greenhouse gas emissions from agriculture are highly dependent on the composition of diets. Tilman and Clark (2014) calculated annual per capita GHG emissions from food production, using the 2009 global average diet as a baseline and comparing this to an estimated global-average income-dependent diet projected for 2050, and to Mediterranean, pescetarian and vegetarian diets in 2050 (see **Figure 3.15**). Global-average per capita dietary GHG emissions from crop and livestock production would increase 32 per cent from 2009 to 2050 if global diets simply continued current trends, responding to the anticipated increases in income around the globe. If adopted globally, the three alternative diets on the other hand, would reduce emissions from food production substantially below those of the projected 2050 income-dependent diet with per capita reductions. These estimations also suggest that shifts in global diets towards more plant-based foods could substantially decrease future agricultural land demand and clearing. Tilman and Clark (2014) note, however, that reducing greenhouse gas emissions does not necessarily contribute to healthier diets; processed foods high in sugar, fats or carbohydrates can have low GHG emissions. Thus, as they note, solutions to the "diet-environment-health" trilemma should aim for healthier diets with low GHG emissions, rather than singularly seeking to minimize GHG emissions alone.

Regional differences in food production systems are striking, particularly between regions that primarily grow crops for direct human consumption versus those that produce crops for other uses such as animal feed or biofuels. Only around 40 per cent of North America and European croplands grow crops for direct human consumption, while the percentage of cropland so allocated in Africa and Asia is over 80 per cent (Foley *et al.* 2011). In addressing strategies to "feed the world", this massive allocation of fertile, productive land in North America and Europe to animal-based agriculture and of extensive pastures in tropical Latin America is increasingly called into question. As Foley *et al.* (2011) note, meat and dairy production can either add to or subtract from the world's food supply. Using highly productive land for animal feeds and biofuel reduces the world's potential food supply, while grazing of livestock on pastures that otherwise are unsuitable for food production, and mixed crop-livestock systems can add both calories and protein to levels of food production, while generating environmental, economic and food security benefits.

Figure 3.14 Per capita consumption of meat in selected countries or regions (Source: adapted from Wirsenius *et al.* 2010)



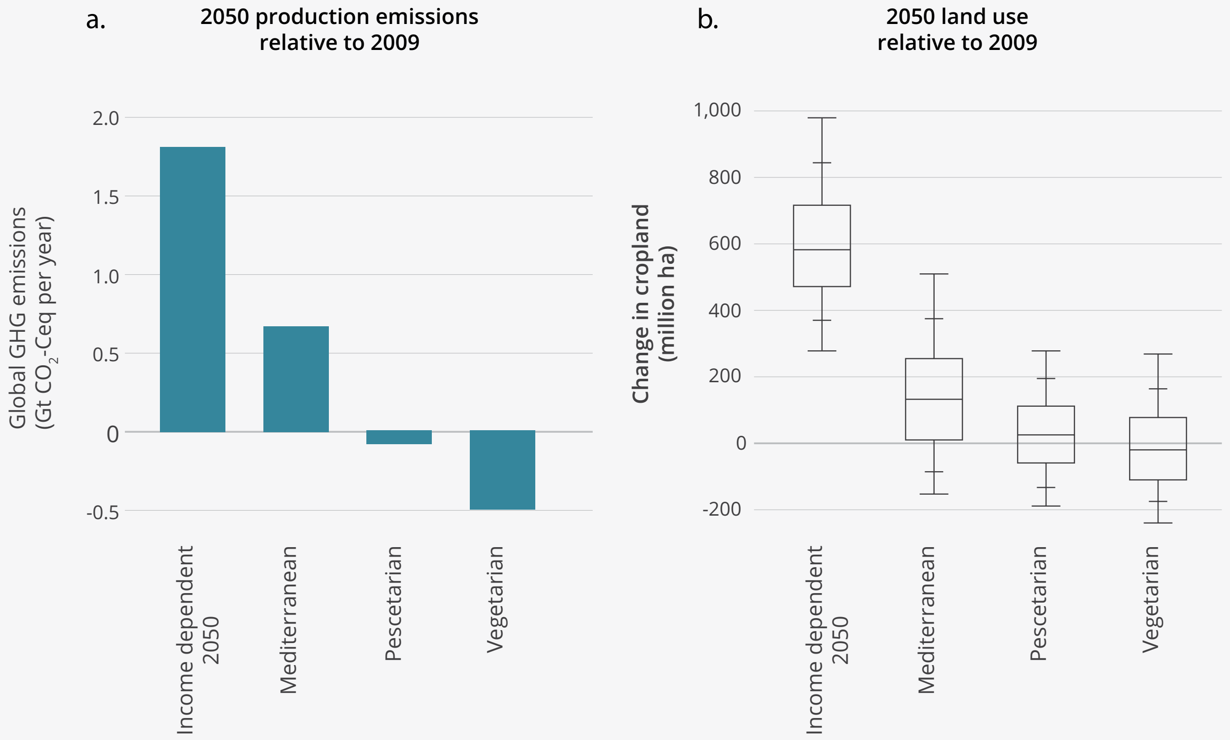
As in any scenario, there are nonetheless important trade-offs to consider: the more unproductive grazing lands are often valuable for wild species of animals and plants, so utilizing them for livestock incurs large costs to biodiversity for minimal benefit in terms of food produced. It has been pointed out that "rewilding" (or restoring to its natural state) the less productive 50 per cent of grazed lands in US would have great benefits for biodiversity yet reduce current beef production by only 2 per cent (Eshel *et al.* 2018). Moreover, scenarios involving more sustainable systems of beef production inevitably hinge on reducing the quantities of meat and dairy production. With large reductions in animal product production, while maintaining some mixed and pastoral systems, environmental benefits can be achieved, but the greatest benefits will come from scaling back the more harmful forms of livestock production, particularly extensive pastures in wet and dry tropical forest regions of Latin America.

3.4.4 Ecological management at system levels

Transitions to sustainable farming systems take place in steps. The diversity of such steps, and a useful typology of resulting farming systems have been recently presented in Therond *et al.* (2017). They suggest a gradient, from the chemical input-based systems of industrial agriculture, based on simplified crop sequences and systematic use of chemical inputs, to biological input-based farming systems, based on still fairly simplified crop sequences but with "environmentally-friendly" inputs and managements such as organically certified fertilizers and precision agriculture, to biodiversity based farming systems, applying ecosystem services as described above, in a whole-system design. It is also recognized, within this gradient, that socio-economic contexts of the food system are also important, a topic we explore below.

TEEBAgriFood posits that pathways to sustainable food systems must look at dependencies and interactions along the entire food chain. Indeed, while place-based ecological management of natural resources to underpin sustainable production is of key importance, analysis across the food chain is of at least the same if not greater importance in order to understand where cost shifts or benefits can be accrued through changes in governance and management. Three examples illustrate the importance of a food chain/holistic system assessment:

Figure 3.15 Effect of diets on GHG emissions and cropland (Source: adapted from Tilman and Clark 2014)



Food waste: while using ecosystem service approaches as outlined above (for nutrients, freshwater use, etc.) can substantively contribute to creating regenerative agricultural ecosystems, addressing food waste in storage or after-market waste could have an equally substantive contribution. If the estimated 30 per cent of food that is lost to waste were not lost, less would need to be produced in the first place, with less use of resources (Gustavsson *et al.* 2011)

An overarching question that should frame holistic analyses is what are we producing, for whom, and why? The consumption of freshwater in connection with livestock production, for example, is a case in point: the amount of water needed to produce food depends on what is being cultivated and the production method. With a growing human population and a shift in dietary preferences toward more meat and dairy, it is always assumed that ever more water will be required. The growth in livestock production, in particular, increases water consumption owing to the extra demand for water to grow crops used to feed livestock. Alternatives, that urgently need consideration, are to work to revise diets for a healthier, and smaller level of meat consumption, and a focus on meat production with less wholesale reliance on feed grains, often shipped from long distances (see case study 3 on meat production in Chapter 8). While livestock production provides much needed protein in critical food insecure regions, its overproduction in many other region has strong impacts on environmental and human health, without contributing to food security.

In a related vein, the 'virtual flows' – of water, nutrients, soil, biomass – as described above, too often are invisible flows, not counted in local environmental assessments. An accurate understanding of food systems should recognise such flows, and their somewhat hidden environmental footprint. A diet based, for example, on less sugar, starch and fat but greater consumption of fish caught by the industrial fishing vessels in waters off West Africa cannot claim high marks for sustainability if the entire "ecosystem service burden" is considered (Pascual *et al.* 2017b).

3.4.5 Holistic assessment of food chains

The contemporary scientific analysis of agriculture is fragmentary, focusing on economic interpretations of agriculture and trade, while disregarding broader relationships to the local and global environment, and social organizations, as well as visible and invisible flows of material and energy. Many aspects are "missing in the frame", which need to be addressed in holistic assessments that TEEBAgriFood promotes.

Missing in the frame: social and environmental aspects: The dominant paradigm of neoclassical economics looks at man as a rational economic entity who, based on the information available, makes rational decisions, maximizes his own benefit and interest, and minimises the risk while achieving the specific goals- usually narrow economic ones. Under this general context, a monetary approach neglects other values. This conventional frame of economics does not include social, cultural and behaviour patterns, or the needs of non-human species (biodiversity). Measures which many capture these elements of overall systemic performance more fully in rural areas could include employability, environmental health, social welfare and well-being, resilience, self-organization, and autonomy.

Missing in the frame: materials and energy in food-value chains: In terms of energy, agricultural systems imply interactions between physical and economical entities. At each stage, it is the added energy, materials and human labour that cause accumulations or losses in the transactions carried out. By introducing an energy analysis into a monetary analysis (Ulgiati *et al.* 1995), may be more evident to see where the benefits of various trade patterns accrue. In an agricultural economy that depends heavily on fossil fuels, both for agricultural inputs, mechanization, storage and transport, the consumption of energy along the food value chain along with associated greenhouse gas emissions, are important attributes impacting sustainability (Siche *et al.* 2008). Material and energy flows and their balances are key points to be considered in a sustainable agricultural and food systems approach; these are generally overlooked in any partial energy analysis. Looking at the complete balance of energy in systems could help to reach to better decisions facing a very complex food system (Fan *et al.* 2018).

3.4.6 Reaping the benefits of food value chains and local trade

In the earlier sections of this chapter so far, the external forces and economic pressures globally have been reviewed, and the resulting invisible flows of resources as a result of these forces and pressures were examined. Further evidence of a global system that is cracking under pressure can be seen in the linkages between conflict, famine, migration, poverty and malnutrition. On local levels, however, there may be more openness and incentives for virtuous cycles that benefit local communities and address their needs for environmental and social sustainability.

Benefits can include culturally appropriate food supplies and closer producer-consumer links with fewer impacts on the environment, while costs of supporting local over global food chains might include a relatively smaller variety of supplied products present in markets and mainly found only on a seasonal basis. It is presumed that through promoting local over global trade, there will be lower negative trade-offs in the economic, social and environmental realms, and reduction of carbon emissions in transport, adding on to sustainability. This does not always hold true, in that, in general, the impacts of production systems are more important in most cases than those of transport (see, for example, Weber and Matthews 2008). It should also be recognized that local has different meanings in different places. Geographical radiuses might vary depending on the area to be supported by local food systems through local trade. Increasingly it is recognized that local food production may provide one means of addressing food crises and food insecurity while reducing the negative social and environmental impacts of food systems. Under economic crises, in developed as well in developed countries, local food production in peri-urban and urban areas is a contribution to helping local communities overcome negative impacts on food systems. Economic crisis, particularly in a context of inflation, tends to worsen market food access for the most vulnerable sectors of the population by exacerbating two main factors: the price of food and the income level.

A number of illustrations showcasing the development of greater capacity for "self-production" or more localized production as lever for community resilience are relevant here. In recent history, Argentina has suffered at least three inflationary crises (1975, 1989-90 and 2001-02). During the second inflationary crisis, a proposal to diversify and increase the dietary quality of the vulnerable sectors emerged. This initiative, named ProHuerta, sought direct food access by self-production of agroecological gardens, and it was initially conceived as a transitional food security project to face the existing social emergency. Regular assessments permitted the documentation of the dietary, social and environmental impacts. In nutritional terms, produce from family orchards provided not less than 72 per cent of globally recommended dietary consumption, and as much as 75 per cent and 37 per cent of vitamin A and C needs, respectively (Britos 2000). In 2016, after twenty-six years of implementation, more than 2.8 million people had been integrated into the Program, involving more than 560,000 family orchards, including 12,000 educational and communitarian orchards. Similarly, under complex socioeconomic and environmental conditions in Haiti, self-production of food showed success in fighting food insecurity, using the methodology and technical approaches of ProHuerta as applied in partnership with several governments and international aid institutions (Canada, Spain, Haiti, Argentina, IFAD, UNASUR, UNDP, WFP and IICA). Between 2005 and 2016 in the context of an extended socio-political crisis, deep food insecurity among local populations and recurrent climatic disasters (hurricanes, tropical storms, floods and droughts), about 260,000 people took an active role in growing orchards across very different agroecological regions of the country. In Haiti, the benefit/cost ratio of the agroecological garden project was four-to-one: for each dollar invested, four were obtained in vegetables produce under the self-production system (Díaz 2015). The effectiveness of this approach on targeting food insecurity promoted the development of similar projects in other countries in the region (Guatemala, Honduras) as well as southern Africa (Mozambique, Angola). In Kenya it was shown that households that engaged in both urban farming and urban based rural agriculture are more food secure compared with the non farming households. Urban farming has a potential of improving household food security and provision of fungible income; hence, the practice should be included in the urban food policies (Onyango Omondi *et al.* 2017).

Cities have often been founded in areas where there is high quality land or good water access, conducive originally to dense farming populations. There are studies that suggest that urban areas will triple by 2030 (UNEP 2014; 2016), and that already, 60 per cent of the world's most productive cropland lie on the outskirts of urban areas. However, urban areas are commonly disconnected from direct relations with the rural areas where food is traditionally produced, as global commodity trade has become a major source of food supplies for urban populations. Recently several efforts have been taken to try to bring locally produced food in nearby areas and supply them, even experimenting with local small-scale urban production schemes. Some have considered a mixed approach between locally produced foods in combination with the acquisition of distant products not found locally (or not in enough amounts for the population numbers involved that must be fed) but always with sustainable schemes. The economic potential of promoting regional and local food systems has been analysed in several parts of the world. In the case of Illinois and its region and its communities, local food systems hold significant potential for economic development (see **Figure 3.15**) and quality of life. Over the last ten years, regional demand for local food has grown 260 per cent, and recent surveys[4] show that three-quarters of Americans prefer that their food is grown locally.

Invisible services and flows in local trade and food systems: The invisible services that local trade and food systems support might include: i) the availability of a diversity of food locally grown under presumably more amicable agricultural practices with lower external inputs, ii) lower negative impacts on the environment, iii) fresh produce available seasonally in local markets, iv) positive inter-relationships between producers, processors and consumers, and a shared construction of knowledge among them, v) better community ties and a feeling of positive dependency; (vi) more and better quality jobs generated locally; (vii) economic spill over at the community and possibly regional level; (viii) identity preservation among the local communities; (ix) local community networks strengthened; and (x) stronger relationships and social economy with the larger territory (Moulaert and Ailenei 2005), among others.

Positive spill over of trading food produced and/or processed locally also includes variables that relate to the "re-valuation and recognition" of the fundamental role that these diverse "actors" (stakeholders, peoples) have played and continue to play towards the common goal of achieving sustainability. The sense of dignity and meaningfulness of rural livelihoods is strengthened when the result of their work is recognized within their larger community.

Benefits from local trade and food security: Local trade has the potential to generate multiple positive benefits. Bypassing the long international supply chains that characterize the conventional food system could allow local trade to positively influence food security by making food readily available, and potentially lead to a healthier and culturally adequate diet, possibly of higher quality with less spoilage (although this final point is under debate, and it is important to look at the entire food system). For example, it has been brought into question just how "local" is the food sold locally, when the inputs for its production and processing may be sourced from long distances (Plassman and Edward-Jones 2009).

Although the need to achieve food security seems to be mainly linked to low-income countries, urban areas throughout the world can benefit from local trade. Supporting the growth of local markets for urban areas can ensure greater access to fresh fruit and vegetables and otherwise healthy (less processed) food options for large populations, especially those that are the most vulnerable.

Value-addition of local trade contribute can be seen in both environmental and socioeconomic respects. With local trade, the local economy may expand, contributing to food security, human health, reduction in carbon emissions, and local employment. As emphasized by Hinrichs (2000), direct agricultural markets play a key role in creating spaces where consumers and producers can interact face-to face. They produce an arena of exchange that is imbued with more social meaning than conventional retail spaces (Pimbert 2015) while creating stronger community bonds and identity.

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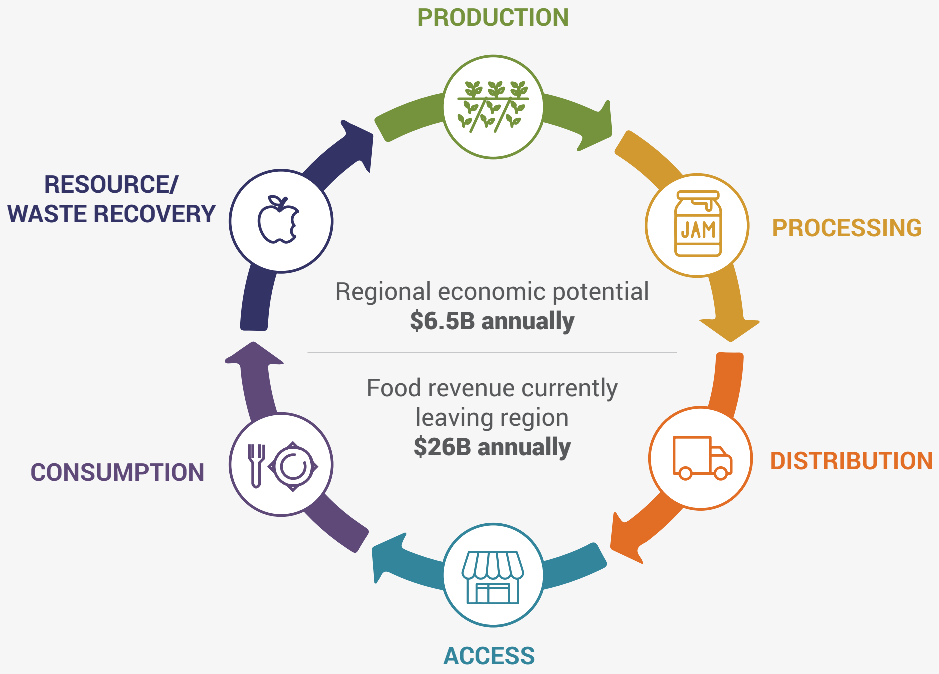
[4] Carried out by United States Farmers and Ranchers Alliance. Findings are reported in Industry Today (2011).

Figure 3.16 Sustainable local food system in Chicago (Source: adapted from CMAP n.d.)



3.4.7 Creating resilience through eco-agri-food systems

Visible and invisible flows currently influence all types of capital globally (human, social, physical and natural) and their interactions, and producing negative and positive effects and flows through time. It is difficult for stakeholders at all points along a food value chain to grasp the implications of invisible flows: for producers, workers, and consumers the impacts of agrochemicals on ecosystem and human health are not thoroughly recognized. Consumer awareness of the health impacts of consuming food enriched with salt and sugar is growing. The performance of different food systems in employing labour, increasing food access and building resilience to shocks are all potential positive value additions that are not always well understood.

Building resiliency in eco-agri-food systems under climate change: IPCC (2014) warns that declining crop yields may already be a fact, and that decreases of 10–25 per cent may be widespread by 2050. FAO (2017b) reports that the degradation of the world's soils has released about 78 billion tons of carbon into the atmosphere. The consensus is that the productivity of crops and livestock may decline because of high temperatures and drought-related stress, but these effects will vary among regions and that solutions come from different approaches and efforts, adapted to local and regional perspectives (FAO 2017b; Hanjra and Qureshi 2010).

Undoubtedly, climate- and weather-induced instability will affect levels of and access to food supply, altering social and economic stability and regional competitiveness. Adaptation is considered a key factor that will shape the future severity of climate change on food production (Altieri *et al.* 2015). FAO is currently developing six farmer field school (FFS) projects on resilience to climate change, with agroecological approaches, in Africa. For example, the Burkina Faso project aims at enhancing the knowledge of 26,000 people through community-based learning and to contribute to the sustainable management of 15 000 hectares of land. A new global agroecology initiative will be launched in 2018 (FAO 2017b). Other global and regional efforts to promote resilience in the context of climate change include REDAGRES, a network of scientists and researchers located in eight IberoAmerican countries funded by the Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo – CYTED, that shares examples of adaptation to climate change in the agricultural sector.

3.5 CONCLUSION

Nature's goods and services are the foundation of agricultural and food systems. Throughout human history, agriculture has co-evolved and developed within different civilizations, which expanded and diversified food systems. Amongst the different human activities, agriculture demands the greatest amounts of land, water, biodiversity and environmental services in order to maintain stability. Depending on how it is practiced, it can either improve or negatively impact the agroecosystem in which it is embedded. Agricultural systems represent a continuum of models from traditional agriculture to modern agriculture, constantly co-evolving, interacting and influencing each other.

We know that agricultural farming—to produce food crops, animal feed, meat, eggs, milk, fibres and biofuels—has transformed the Earth's capacity to support people, and at the same time has had a significant impact on the habitability of the Earth for the rest of biological diversity. Agriculture is by far the leading cause of deforestation in the tropics and has already replaced around 70 per cent of the world's grasslands, 50 per cent of savannahs and 45 per cent of temperate deciduous forests (Balmford *et al.* 2012).

Understanding agricultural and food systems requires an approach that appreciates complexity, where ecological, social, cultural and economic issues interact and influence together in different ways, and take into account the effects of production systems at a landscape scale.

The issue of governance of food security in a globalized world is very complex. It involves multiple layers of decision-making and creates a need for coherent policies. The capacity of single households to ensure an adequate supply of food for its members is affected by both local and global conditions. Decisions that affect the food security of the population of a country involve many social and political forces at multiple levels: the state, businesses, and civil society.

International trade in agricultural goods and the global food system have produced important externalities that have not been fully quantified, or have been assessed only in monetary terms. The analysis of stocks and flows of materials and water and the incorporation of these invisible elements, such as rucksacks and virtual flows, can contribute to a comprehensive understanding of the process in the food chains and to the promotion of a more sustainable use of resources in the eco-agri-food system.

We have seen in this chapter that despite tremendous external forces and economic pressures, traditional and mixed food systems sustain around two-thirds of the global production of commodities and nutrients, and do so within diverse farming landscapes. The potential is substantial, to build on existing food systems, - each with differing attributes- to strengthen forms of agricultural production that explicitly enhance resilience and the natural capital that underpin food systems, creating regenerative forms of agriculture and food that generates multiple positive externalities.

Present global food systems today present distortions that convey both hunger and excesses. It will take investments and efforts on the part of all stakeholders to bring about the radical shift of global agricultural and food systems that is needed. Investment in environmental and nutritional education, together with the promotion to switch to healthy and nutritious diets is essential. Food producers must be socially recognized for their relevant service to the society. Nutritious food, produced with ecosystem services that minimize or eliminate external inputs must be valued for the society for its full benefits and reduced costs.

Governments of countries that aim to restore healthy agricultural systems and promote nutritious and culturally anchored diets must lead the change in global food systems. Corporations also have a role to fulfil, but the shift must be driven by the states. Social organizations of consumers, users, farmers and other NGOs, each with specific social and environmental claims, crucial role to play in changing present social habits at both national and global scales.

Global society – whether taking the perspective of the private sector, governments or civil society - can find in the identification of the intangible and invisible stocks and flow the central elements to understand the integral processes of the complexity of the global food system. Greater insight into these processes can help the public to promote the sustainable use of the natural resources, biodiversity and environmental services in creating eco-agri-food chains with multiple benefits. Public policies, technology and investment possibilities can enhance the promotion towards sustainable food systems, creating opportunities for all farmers, consumers, corporations and countries.

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