

CHAPTER 4

HUMAN HEALTH, DIETS AND NUTRITION: RECOGNIZING AND INTEGRATING VITAL MISSING LINKS IN ECO-AGRI-FOOD SYSTEMS

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SUMMARY

Chapter 4 outlines ways in which the food system impacts human health - directly or indirectly, negatively or positively – as well as food and nutritional security. It is illustrated how human health is compromised throughout our current food system both for end-point consumers and for those working along the supply chain. This chapter explores a number of endpoints in various food system strategies and creates a context for exploration, mitigation, change, and ultimately transformation of our global food system to one in which health – of humans, ecosystems, and communities – is the norm. We also illustrate ways in which various trends (e.g. climate change, fresh water, demographic shifts) alter the challenge of improving human health via food system activities.

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CHAPTER 4

4.0 KEY MESSAGES

- The purpose of this chapter is to explore ways in which current agri-food approaches impact food security, nutrition and human health and to develop options for transforming these systems into eco-agri-food systems that promote human and ecological health.
- Human health is directly linked to and influenced by food and nutrition security, all of which are hugely important (and largely ignored) considerations when evaluating the impacts and externalities of eco-agri-food systems.
- There are five key channels through which food systems negatively impact health: occupational hazards; environmental contamination; contaminated, unsafe, and altered foods; unhealthy dietary patterns and food insecurity.
- Eco-agri-food systems can be either enablers or disablers (i.e. have either positive or negative impacts and externalities) in terms of health and food/nutrition security, depending on a variety of factors that influence what, how and how much food is produced, processed and consumed.
- The challenge to accomplishing sustainable, universal food and nutrition security is multi-faceted and will depend on four interrelated developments: dietary pattern change, social justice, food waste and appropriate technological development.
- Six of the top ten risk factors driving the global burden of disease are diet-related with the quality of life for billions of people impacted by malnutrition.
- Lives and livelihoods can additionally be impacted via food system work-related injuries or deaths or exposure to toxins/pathogens. There are also indirect impacts now and for future generations.
- Population increase, urbanisation and modernisation continue to negatively impact human health and food/nutrition security, for example with 1.9 billion people currently overweight or obese, whereas more localised, traditional systems can offer important lessons for having positive impacts.
- Harvest and post-harvest management of crops and animal products is critical to ensuring food can be consumed without contamination (chemical or biological) and with minimal losses and decline in nutritional quality.
- Projected dietary pattern shifts – the nutrition transition - will place an unacceptable burden on ecosystems and natural resources as well as chronic disease incidence.
- Several Sustainable Development Goals are directly linked to human health and food/nutrition security, with all of them indirectly linked, and this analysis can be used as part of their 'toolkit for resolution'.

CHAPTER 4

HUMAN HEALTH, DIETS AND NUTRITION: RECOGNIZING AND INTEGRATING VITAL MISSING LINKS IN ECO-AGRI-FOOD SYSTEMS

4.1 INTRODUCTION AND THE TEEBAGRIFOOD EVALUATION FRAMEWORK

Let us start by imagining a future where all forms of malnutrition are eliminated (SDG 2) and we have achieved low levels of obesity/chronic disease globally, with greatly reduced levels of acute disease (SDG 3). The world is composed of connected webs of cooperation across regions, ensuring diversity, resiliency, and global communication (SDG 17). Food systems across the globe provide good livelihoods for those engaged in the production, processing, transportation, storage, and marketing of foods, as well as the management of compostable and reusable waste. The food system is doing its part to eliminate poverty (SDG 1) and provide decent work and economic growth (SDG 8). Women have the same rights and rewards as men in this system (SDG 5), with strong educational institutions (SDG 4) supporting sustainable and healthy consumption patterns. While the majority of people live in urban areas, there are robust urban-rural relationships that ensure food security for all urbanites, while industries supply healthy processed foods, as well as appropriate, responsible technology required in the production, processing, storage, and movement of food supply (SDG 9). Advertising and market placement are skewed to promote healthy dietary patterns, which helps ensure both food and employment security – markedly reducing the threat of urban uprisings (SDG 16), aiding in sustainable city development (SDG 11), and reducing inequalities (SDG 10). The cycle of production and consumption is completed responsibly (SDG 12) with the use of renewable materials and energies – available to all (SDG 7) – and making use of materials and practices that preserve fresh water and provide clean water (SDG 6). Our lands and waters are preserved for humans as

well as the flora and fauna we rely upon (SDG 14 and 15). All of this ensures that our global food system does not contribute to increasing climate change – but rather acts as a tool for resolution (SDG 13). In other words, from a human health perspective, the SDGs provide a series of goals, the TEEBAgriFood Framework provides a system for analysis (as outlined in Chapter 6), and a network of food systems embedded in regions across the globe provide a strategy for securing a future for healthy people. This scenario is not feasible or possible without recognizing food as a human right and food security as an entitlement for all people (Sen 1986). In the remainder of this chapter, we show how human health is compromised throughout our current food system, and reciprocally, how human health impacts our ability to engage broadly in society and in the food system itself.

While there are many factors contributing to human health, none has quite the impact of the food we consume. Six of the top 11 risk factors driving the global burden of disease are related to diet (GBD Study 2013 Collaborators 2015). The quality of life for billions of people is impacted by malnutrition (i.e. undernutrition, including deficiencies of essential vitamins and minerals, or by being overweight/obese). Undernutrition, often coupled with infectious disease or parasites, causes stunting, wasting, and diet-related non-communicable diseases (NCDs). Malnutrition associated with diets represents the number one risk factor in the global burden of disease (IFPRI 2016). Globally, maternal and child malnutrition represent the leading cause of disability-adjusted life years (DALY) with dietary risks being the second leading cause (GBD 2016 Risk Factors Collaborators 2017). Malnutrition reduction is not simply a matter of healthy food access – although this is certainly a major contributing factor.

TEEBAgriFood applies a systems thinking approach (see Chapter 2) to understanding the totality of agricultural production, food supply chains, and various institutional policies and practices, which in turn greatly impact an

individual's human health as well as their ability to make food pattern changes. The term "eco-agri-food" system is introduced in this report (see Chapter 2 and Chapter 3) as a descriptive term for the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labor, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food. Across the food system, people are additionally impacted in a variety of ways via work-related injuries (or death) or toxicant/pathogen exposure. Coupled with these direct impacts are indirect impacts, both current and future.

Within the field of public health, the social-ecological model has demonstrated that the interaction between people and their environments is instrumental in shaping individual behaviour (Sallis, Owen and Fisher 2008; Golden *et al.* 2015; Story *et al.* 2008; Golden and Earp 2012), which in turn affects individual and community health outcomes. The food system can either positively or negatively impact food/nutrition security, livelihood procurement, and environmental sustainability across communities. Through the policies, regulatory practices, and social networks that shape the food system, we can see either one outcome where high-calorie, low nutritional content foods are easily procured, or another outcome in which it becomes much easier to consume greater amounts of fruits, vegetables, whole grains, and other healthier foods. In the same vein, we can develop food systems that either allow a relatively large number of individuals to secure a livelihood or one in which large numbers of workers are systematically exploited while a few benefit financially.

The purpose of this chapter is to explore ways in which our eco-agri-food system impacts human health and food and nutritional security, and to explore this as a key point of impact within the context of the TEEBAgriFood Evaluation Framework. This chapter explores a number of endpoints in various food system strategies and creates a context for exploration, mitigation, change, and ultimately transformation of our global food system to one in which health – encompassing that of humans, ecosystems, and communities – is the norm for the 9-10 billion people by 2050, the medium UN population projection for that year. The TEEBAgriFood Framework provides a strategy and process for incorporating a full array of potential health impacts – both positive and negative – into understanding eco-agri-food system best strategies. From production through to consumption, there are myriad methods and practices involved in the food value chain. Each influences the health status of people and the environments in which they live. The TEEBAgriFood Framework examines each link in the value chain to help determine best practices that will optimize community value.

4.2 HUMAN HEALTH – DEFINITION AND SCOPE WITHIN AN ECO-AGRI-FOOD SYSTEM PERSPECTIVE

While the World Health Organization (WHO) definition of health as "a state of complete physical, mental, and social well-being, not merely the absence of disease or infirmity" (WHO 1946) was radical for its time, today it seems lacking. Experts have more recently defined health as "the ability to adapt and self manage in the face of social, physical, and emotional challenges" (Godlee 2011; Huber *et al.* 2011). In order for this to happen, people must be food- and nutrition-secure. Food and nutrition security "exists when all people at all times have physical, social and economic access to food, which is safe and consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life" (CFS 2012). In order for individual food security to exist, we argue that community food security across the global community is a necessary precondition. Community food security has been defined as a scenario where "all community residents obtain a safe, culturally acceptable, nutritionally adequate diet through a sustainable food system that maximizes community self-reliance and social justice" (Hamm and Bellows 2003; Bellows and Hamm 2003). We know of no community globally that would meet this definition.

Looking in the broadest terms, there is wide disparity in human health across the globe. Although a poor surrogate for health, global life expectancy gives some idea of these global disparities. Global life expectancy at birth in 2015 was 71.4 years (73.8 years for females and 69.1 years for males), ranging from 60.0 years in Africa to 76.8 years in the Europe (WHO 2017e). Healthy life expectancy (HALE, which takes morbidity into account, as life expectancy does not) (WHO 2014b) varies markedly at birth from a low range of 29.5-37.3 years in many African countries to 67.9 to 73.8 in a number of developed countries (Mathers *et al.* 2001).

These variations are due to a number of causes - non-communicable disease (NCD) being one very important contributor. Both undernutrition and being overweight or obese (as well as a host of other factors within and outside the agri-food system) play a role in whether an individual develops NCDs (Nishida *et al.* 2004; Darnton-Hill *et al.* 2004). Influences contributing to NCD development are part of a continuum, i.e. risks begin in fetal life and continue into old age (Nishida *et al.* 2004). For example, poor nutrition in utero and in infancy can lead to stunting

and impaired neural pathway development affecting a person throughout life. NCDs suffered in adulthood reflect, in part, cumulative differential lifetime exposures to various damaging environments in concert with individual genetic predispositions. The criteria are now better recognized and occur at a far higher rate in the populations of the developing and transitional worlds (WHO and International Longevity Centre - UK 2000).

We most typically consider health impacts in respect to supply-chain endpoint consumers. Unhealthy dietary patterns where excess calories are easily accessible is a risk factor in the etiology of several leading causes of mortality and morbidity (IoM and NRC 2015) and greatly impacts the global burden of disease (GBD 2016 SDG Collaborators 2017). Mortality and Disability Adjusted Life Years (DALYs) lost are impacted by various diseases, some arising from issues related to food consumption (GBD 2016 Risk Factors Collaborators 2017).

Three metabolic factors that are at least partially attributable to dietary patterns – high systolic blood pressure, high fasting plasma glucose, and high body-mass index - account for the largest number of metabolically attributable DALYs globally (GBD 2016 Risk Factors Collaborators 2017). Across the supply chain, occupational hazards, environmental contaminants, and pathogenic/parasitic exposures also contribute to DALYs, in addition to unhealthy dietary patterns and undernutrition of various types (IPES-Food 2017). These issues will be explored in more detail below. For now, consider the array of hazards, contaminants, and exposures that both workers within the food supply chain and food consumers are subject to: farmers, farm workers, and supply chain workers experience a number of workplace hazards related to work conditions, institutional policies, and social norms. Consumers are similarly exposed to a range of hazards and contaminants and may also have a co-existing disease/parasitic infection and/or lack access to foods that enable healthy dietary patterns.

4.3 SUSTAINABLE DEVELOPMENT GOALS, HEALTH AND THE ECO-AGRI-FOOD SYSTEM

The 2030 Sustainable Development Agenda has 17 Sustainable Development Goals (SDGs) and provides an opportunity to build better systems for health in part by recognizing that health depends upon and supports productivity in other key sectors such as agriculture, education, employment, energy, the environment, and the economy (WHO 2017e). Therefore, health contributes

to and benefits from all the other SDGs (UN GA 2015), and if achieved, the SDGs will also strengthen a number of determinants of health, such as gender equity and education.

Accounting for the food system as both the means of provisioning good nutrition and a recipient of positive nutrition and health outcomes (e.g. greater labour productivity) is reciprocally necessary in order to achieve the SDGs (UNSCN 2015). The UN General Assembly declared 2016-2025 as the Decade of Action on Nutrition, specifically referencing the Rome Declaration on Nutrition (FAO and WHO 2014b) and its Framework for Action (FAO and WHO 2014a) with sixty recommendations. These documents specifically address the need for sustainable food and agricultural systems. For example, the Rome Declaration states, “food and agriculture systems, including crops, livestock, forestry, fisheries and aquaculture, need to be addressed comprehensively through coordinated public policies, taking into account the resources, investment, environment, people, institutions and processes with which food is produced, processed, stored, distributed, prepared and consumed”. Some recommendations specifically address components of the food system while others address the institutions, policies, and practices that govern (or fail to govern) it. The adoption of the 17 Sustainable Development Goals and the declaration of the Decade of Action provide a set of global targets that dovetail well with the TEEBAgriFood Evaluation Framework.

Considering the source of food products, the supply chains involved in moving food products from growth and processing to the consumer, and various retail points that convey goods to the end user, there are four overlapping and intersecting types of food systems in any community (Gomez and Ricketts 2013) that we will use for the purposes of this discussion. These can be framed as:

- Traditional
- Traditional-to-modern
- Modern-to-traditional
- Modern

In other words, food can be grown and produced within the region and enter either a traditional supply chain with a retail point-of-sale that is, for example, a traditional market (traditional), or a retail supermarket (traditional-to-modern). On the other hand, a highly processed product (e.g. soda) can originate via a global supply chain and end either at a traditional market (modern-to-traditional) or a retail supermarket (modern). These are admittedly very broad, brushstroke framings for a typology, but will suffice for our purposes.

At the beginning of this chapter an aspirational scenario was presented linking all the SDGs and outlining ways in which the eco-agri-food system could positively impact

them all. A consideration of the 17 SDGs, in their entirety, couples nicely to the TEEBAgriFood Framework, but two SDGs are the most congruent with the discussion of health and the food system: SDG 2 (zero hunger) and SDG 3 (good health and well-being). SDG 2 has eight targets focused on various aspects of agricultural production and hunger/malnutrition targets. While SDG 3 does not explicitly include food, a number of the targets are dependent upon a well-functioning human immune system, which inherently requires consumption of a healthy diet on a daily basis. SDG 3 aims to ensure healthy lives and promote wellbeing for all across their lifespan, and it has 13 specific health targets with target 3.4 focused specifically on reducing premature mortality from NCDs by one-third.

4.4 POPULATION INCREASE AND URBANIZATION IMPLICATIONS FOR HEALTH, FOOD SECURITY, AND SUSTAINABILITY

The growing world population is a crucial factor when examining the future of the food system. Population increases matter not only when it comes to global carrying capacity but also per capita environmental impact in specific geographic locales, and discrepancies in factors like education and fertility (Crespo Cuaresma *et al.* 2014). How we react to the burden of more people globally – as countries, as communities, and as individuals – will determine much of how the future unfolds.

Numbers illustrate only one part - but an important part - of the story. Estimates vary but a global population of 9.8 billion by 2050 and 11.2 billion by 2100 is likely – with a 95 per cent confidence range of 9.4-10.2 billion in 2050 and 9.6-13.2 billion in 2100 (UN DESA 2015) Could 9.8 billion people, predominantly living in urban areas, be fed sustainably and consume healthy, culturally secure meal patterns? The simple answer is: it depends.

The vast majority of the global food supply is currently produced by rural farmers. How much of the world's food supply is produced by small holder farmers is contested with "70%" the oft-cited number¹. More than half of the world's population now lives in urban areas (see **Figure 4.1**)

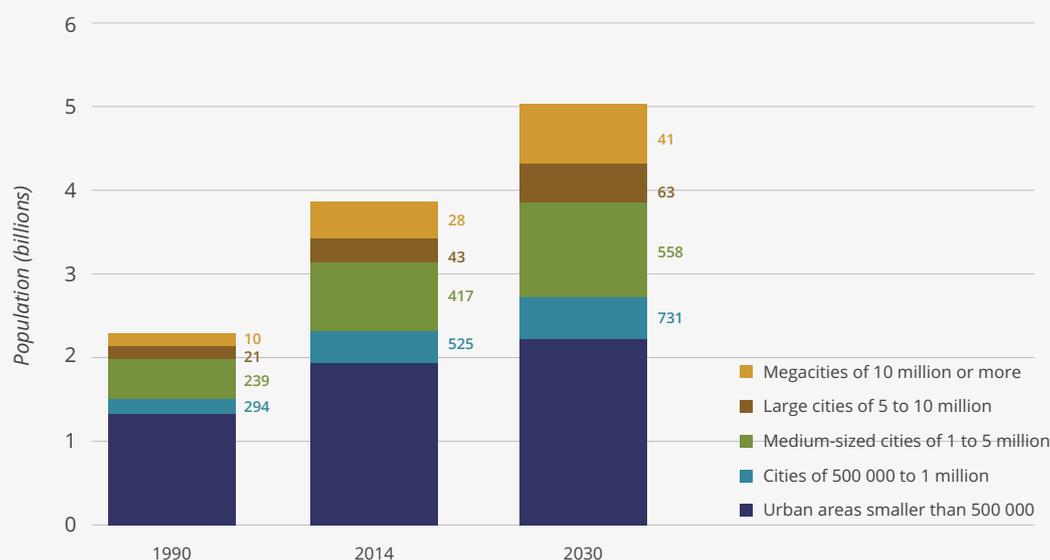
– and movement to urban areas will continue as manifested by projected growth in cities of all sizes. As the 21st century unfolds, rural farmers will need to supply a greater number of consumers per capita to ensure food security and a daily healthy diet. At the same time, larger numbers of people are further from the points of food production and supply chains than in the past. Infrastructure needs to expand to ensure food security for urban numbers approaching 66 per cent of the global population by 2050 (UN DESA 2015). In low-income countries across the globe, the incidence and percentage of rural poor is higher than urban poor (Alkire *et al.* 2014), and the largest percentage of these rural inhabitants are farmers. At the same time that demands on farmers are increasing in terms of food production, the rural population is aging (as many youth migrate to urban centres), and experiencing significant inequality when it comes to their own food security and other measures of well-being. This results in a growing inequality, where rural farmers are living alongside and supplying food to urban populations that are overconsuming calories and other resources (leading to higher obesity rates and other health issues), potentially resulting in civil unrest.

The previously posed challenge to accomplishing sustainable, universal food and nutrition security is multi-faceted – moving from "it depends" to "yes" will depend on four interrelated developments:

1. Dietary pattern change: On average, the more meat and dairy products consumed per capita, the more land, fertilizer, and water required for production.
2. Social justice: The distribution of food is currently much more problematic than the absolute amount of food produced. In addition, achieving gender equity could unleash tremendous human development potential – much of it directed at food production and/or food system livelihoods.
3. Food waste: Cutting waste significantly across the globe could have a significant impact on food security and future production needs.
4. Technological development: The ability of small holder farmers to increase productivity without increasing labour could be a key to food security in urban areas. Enhanced agroecological strategies coupled with improved labour-saving equipment is critical.

¹ For an interesting discussion of the generative nature of '70% of the world's food is produced by small holder farmers' see: www.researchgate.net/post/Smallholder_farmers_produce_70_per_cent_of_the_worlds_food_Whats_the_source_for_this_number

Figure 4.1 Global urban population growth is propelled by the growth of cities of all sizes (Source: adapted from UNDESA 2015)



The TEEBAgriFood Framework provides a strategy for examining these four dimensions. In this section we look at each of these in a bit more detail relative to environmental sustainability.

Dietary Patterns: Current dietary patterns for much of the developed world are not sustainable and will be environmentally very deleterious if continued and expanded globally (Nelson *et al.* 2016). This is especially true of growth in meat supply as seen in **Figure 4.2**

Per capita meat consumption varies from 4 kg/year in India to 117 kg/year in the U.S. As seen in **Figure 4.2**, the global per capita consumption has increased from 23 to 42 kg/year between 1962 and 2009. If 9.7 billion people were to eat like a typical American., it will require approximately an additional 309 billion kilograms of edible meat production per year; this is about 1.2 billion more cattle if all came from beef, or 161 billion more chickens if it all came from poultry (in both cases using average slaughter and edible meat rates for typical U.S. production but without accounting for food waste² . Even at very high per-acre feed yields, this would require vastly more land (Meeh 2011)– 1.59 billion hectares if all beef or 184 million hectares if all broiler chickens. With about 49 million km² of global agricultural land (World Bank Data) (about 4.9 billion hectares), this would imply a 36 per cent increase in agricultural land for cattle production or a 4.2 per cent increase for broilers (at Michigan, USA feed production/hectare levels, an optimistic assessment and without accounting for wasted food). This

would only happen at great expense to currently forested lands, which would require clearing in order to grow feed, with severe repercussions regarding greenhouse gases (GHGs), biodiversity and water pollution.

That said, some have argued that shifting ruminants to management-intensive grazing, a strategy of high density grazing with frequent movement, would result in net carbon sequestration and a shift for ruminant production from a net GHG emitter to a net GHG sequester thanks to alterations in the soil and plant/plant root dynamics in these grazing areas (Teague *et al.* 2016; Stanley *et al.* 2018). It would also reduce sediment and nutrient runoff. It is not clear, however, for how long these effects would be seen; there is reasonably an asymptote to the total carbon sequestration per hectare. No matter how ruminants are produced, the *amount* of meat consumed in most of the developed world is environmentally unsustainable and related to negative health outcomes including cardiovascular disease (Potter 2017), and if adopted by 9.7 billion people would be very problematic – the quantitative per capita level is critical to the balance of human nutrition and environmental sustainability.

There is a strong nutrition transition occurring globally (Popkin *et al.* 2012; Popkin 2017) – one facet of which is increasing per capita meat consumption – and it is not practical, feasible, or sustainable for the global population for this trend to continue. Garnett and Strong (2012), on behalf of the Green Food Project and building on the work of many including McMichael *et al.* (2007), have suggested principles of healthy and environmentally sustainable eating that include:

² Calculations based on Meeh *et al.* (2013) study in Michigan, USA

- Moderating meat consumption, and increasing intake of peas, beans and other pulses, tofu, nuts, and other plant sources of protein.
- Decreasing the amount of milk and dairy products in diet and/or seeking out plant-based alternatives, including those that are fortified with additional vitamins and minerals.

One underexplored avenue that is gaining traction is the use of insects as a protein and micronutrient source (van Huis *et al.* 2013). FAO suggests a number of benefits environmentally, nutritionally, and socially including their high feed conversion ratio with low land use as well as high nutritional content (Halloran and Vantomme 2014). While a number of cultures have long included insects in their dietary patterns, only recently is the practice gaining traction as a potential global food source. Researchers caution that while it appears that raising insects for food generates a much lower environmental footprint than other creatures there is a need for more extensive life cycle analysis (Halloran *et al.* 2016) as well as other research (Halloran *et al.* 2015).

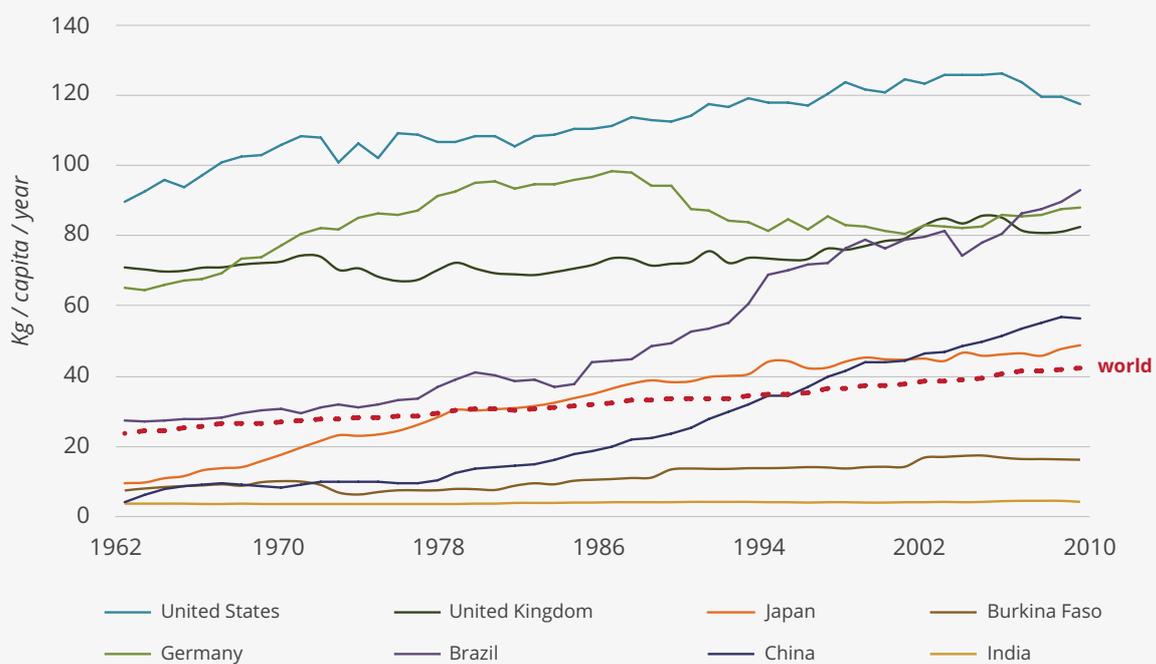
Social Justice: What aspects of a food system encourage greater social justice? Do the structure and relationships underlying certain typologies tend towards greater social justice? The research is clear that an important

component in malnutrition is women’s status in a given society (IFPRI 2016).

In the developed world, there is evidence that a combination of community-based solutions and governmental policies can help move us towards greater dietary diversity – and hence healthier diets. Evidence of enhanced food security is not yet evident as most of the case examples are too small and locally restricted at this point. But by means of example, in the U.S. wireless technology has allowed for the use of food stamps at farmers’ markets. This, coupled with state government cost support, has rapidly escalated access to fresh produce by low-income households (Smalley 2014). In addition, a further expansion of access has occurred through the development of “Double-Up Bucks” programs across the country (Fair Food Network 2017). This program started with philanthropic funds in a few states and has now expanded to 23 of the 50 U.S. states. It doubles the value of a customer’s food stamps for fresh produce. Importantly, it was incorporated into the last U.S. Federal Farm Bill to provide grant funds annually for the creation and management of these programs. These largely run via regional supply chains (final point-of-sale are typically farmers’ markets).

Outside the U.S. there are a wide range of social justice programs focused on aspects of the food systems. These are extensively outlined in Chapter 5.

Figure 4.2 Development of meat supply over time (Source: adapted from Stoll-Kleemann and O’Riordan 2015)



Food Waste: FAO estimates that approximately 32 per cent (on a weight basis) of all food is wasted (Lipinski *et al.* 2013). This topic is approached in more detail in Section 4.10. With population growth and urbanisation it is even more critical to reduce wasted, edible food in order to improve nutritional status and reduce environmental stress.

Appropriate Technology: Appropriate technology development in service of farmers and others in the food supply chain is critically necessary as populations urbanize. Whether in the developed or the developing world, small-scale farmers share the problems of access to markets, access to credit, the need for improvements in agroecological farming, and demand for increased production without a near-linear increase in labour requirements, all without a resultant increase in GHG release.

Using Africa as an example, it has become a net food importer (Rakotoarisoa *et al.* 2011), a fact primarily driven by population growth. This population growth since the late 1990s has primarily occurred in urban areas with the rural population fairly static, but aging. Reversing Africa's food import status would require the rural farming population to become more productive, i.e. to produce more food per capita and/or create less waste. One aspect of this would be the increased use of mechanization, powered by renewable sources of energy. There are several promising technological developments that could help, including increasingly cost competitive rural renewable power charging hubs. Electric tractors are under development (see Solectrac website (2018), for example) with potential for improving the efficiency of small-scale farmers across the globe. In the context of the TEEBAgriFood Evaluation Framework, it must be asked: are the improvements that such technology enables better suited for smaller-scale, more regionalized production, or would they also provide benefits at the larger scale of globalized production where far greater horsepower is needed? Can policies and support mechanisms be developed so that technologies such as these become widely available and usable by small-scale farmers?

As described earlier, there are several possible pathways to supply food for an increasingly urban world. Urban development can build on pre-existing traditional markets and ensure that whole foods required for health are available in sufficient amounts and of high quality for consumers. These smaller markets, while also offering highly and moderately processed foods, tend to have a high proportion of raw foods. An alternate route would be supporting large numbers of supermarkets at the expense of traditional markets with regional supply chains. This model, one espoused by much of the developed world, means high-sugar and high-fat (i.e. high caloric density) foods will be plentiful and less costly than nutrient-dense foods (Drewnowski and Specter 2004). Researchers

(Rischke *et al.* 2014; 2015; Kimenju *et al.* 2015) have identified the proliferation of supermarkets in both rural and urban Kenya as a strong contributing factor to the increasing obesity rates due to the availability and relative affordability of high-calorie, highly processed foods. They suggest that supermarkets are associated with the nutrition transition and the emergence of obesity in small Kenyan towns and a higher body mass index among adults. The trend is not observed in children and adolescents, where it seems to reduce their undernutrition.

4.5 OVERCONSUMPTION: A CRITICAL THREAT TO HUMAN AND ENVIRONMENTAL HEALTH

Our food system and associated dietary patterns impact the environment in a variety of ways, and what and how much we eat impacts how rapidly we reach planetary boundary limits – including excess greenhouse gas emissions, biodiversity loss, water quality degradation, water availability, land use patterns, and landscape degradation.

Excess calorie and/or excess protein consumption is the most obvious and arguably the most environmentally impactful of our dietary patterns. Current Western-type diets, with high intakes of meat, fat and sugar represent a major risk to health, social systems and environmental life support systems (SCAR 2011; Lim *et al.* 2012; Aleksandrowicz *et al.* 2016; Global Panel on Agriculture and Food Systems for Nutrition 2016). The average person in more than 90 per cent of the world's countries had daily per capita protein consumption that exceeded estimated dietary requirements in 2009 (Ranganathan *et al.* 2016). While 465 million people were reported as underweight in 2014 (WHO 2018c), 1.9 billion adults were overweight (including obese) (WHO 2016b). Most of these overweight or obese are in the developing world (Keats and Wiggins 2014), showing how deeply a nutrition transition leading to Western-pattern diet adoption has permeated. In the U.S., the average person consumes about 2,200 total calories daily (USDA 2014). For women there has been an average increase of about 335 calories per day, and for men about 168 calories per day between 1971 and 2000 (Wright. *et al.* 2004)³.

To give a sense of the excess production (and attendant drain on natural resources) required for this level of consumption, let us assume for a moment these calories

³ It is assumed these are excess calories – mostly in the form of sugar and fat – since the U.S. obesity rate was very low in 1971 and increased markedly during this period.

come from high fructose corn syrup and corn oil (which are indeed among the most over-consumed products). Industry can extract about 42,100 calories of high fructose corn syrup and about 6,200 calories of corn oil per bushel of corn. In this scenario⁴, assume corn production of 420 bushels per hectare (Nielsen 2017) – the approximate average U.S. production in 2016. Excess consumption over 325 million U.S. residents with 126 million adult women and 120 million adult men means that a minimum of 1.1 million hectares of corn production is needed just for direct excess calorie consumption (there are about 36.4 million hectares grown in the U.S.). These extra hectares lead to soil loss, phosphorus runoff, nitrogen contamination of water wells for rural residents, and loss of wildlife habitat.

If we extrapolate this to the world, 7.6 billion people consuming that many *extra* calories implies a need for about 94 per cent of the total U.S. corn production, a conservative estimate for several reasons. First, this calculation assumed direct calorie consumption of vegetable-based products as opposed to consumption of animal-based calories with attendant inefficiencies. Second, while many of these excess calories are consumed, a percentage is lost as wasted food – the food wasted, with the extra calories available, is not accounted for in these calculations. Third, in the global calculations U.S. average corn yields are used. Average global corn yields are about half the U.S. average, requiring closer to 66 million hectares of corn production to grow the extra calories if none are lost in the supply chain – a good deal more when losses are considered.

Economic development, globalization, urbanisation, and changing lifestyles are linked to a shift towards poor-quality diets, excess caloric intake, and low levels of exercise, leading to a rapid increase in obesity and NCDs globally (Hawkes 2006; Kjellstrom *et al.* 2007). These consumption patterns are related to the food system type/structure in which food consumers exist, as well as changes in income status.

4.6 AGRICULTURE'S ROLE IN A HEALTH-PROMOTING FOOD SYSTEM

The food system starts with agricultural production and the range of inputs supporting it. Without production there is no food. The quality and type of food and diets available is both a result of what agriculture is producing and how such production is being undertaken (Fanzo

et al. 2013) as well as the transformation of crops into processed foods. Agriculture has significantly changed in the past century from a system where diverse farms produced a wide variety of crops and animals to one marked by more and more specialized farms producing one or a few major crops, especially cereals and feed crops. Industrialized agriculture has not only transformed the agricultural landscapes in high income countries and economies in transition, but is also the dominant model being promoted in agricultural development programs in low-income countries (IPES-Food 2016).

The rise of industrial agriculture has had impacts on the nutrient content of diets. Indeed, agricultural policies that promote specialization in energy-rich staple cereals have corresponded with a decline in consumption of pulses and other minor crops with high nutritional value (Hawkes 2007; DeFries *et al.* 2015). Industrial agricultural systems have never been explicitly designed to promote human health and, instead, primarily focus on increased productivity and profitability for farmers and agricultural industries (Bouis and Welch 2010). Breeding programs for the major crops have focused mainly on productivity increases (Haas *et al.* 2016). The result of this evolution has been the production of large quantities of relatively inexpensive energy-rich, nutrient-poor food that represents an increasing proportion of food intake.

For instance, data indicates that winter wheat yield increases are concurrent with decreases in selenium, zinc, and iron content (Fanzo *et al.* 2013; Garvin *et al.* 2006). Between 1950 and 1999, 43 garden crops have shown declines for six nutrients (protein, Ca, P, Fe, riboflavin, and ascorbic acid). Those showing median declines ranged from 6 per cent for protein to 38 per cent for riboflavin (Davis *et al.* 2004). This will likely be exacerbated by climate change with additional losses in crop nutrients (Myers *et al.* 2017).

Global land area devoted to high-yielding cereals increased over the past 50 years, with rice, wheat, and maize collectively increasing from 66 per cent to 79 per cent of all cereal area between 1961 and 2013. This was at the expense of other cereals, many with higher micronutrient contents: barley, oats, rye, millet, and sorghum collectively declined from 33 per cent to 19 per cent of total production (FAO 2018). The iron content of millet is nearly four times that for rice. Oat zinc content is more than quadruple wheat (DeFries *et al.* 2015).

In the last decade, increasing awareness of the crucial role that agriculture can play in improving the nutritional quality of food and diets has led to the notion of nutrition-sensitive agriculture, a concept that aims to narrow the gap between available and accessible food and the food needed for a healthy and balanced diet for all people (Jaenicke and Virchow 2013). Two main tracks have been followed: biofortification and diversification.

⁴ Calculations in this section are by the Coordinating Lead Author.

Biofortification is the process of increasing the density of micronutrients such as pro-vitamin A, iron, and zinc in crops through plant breeding, transgenic techniques, or agronomic practices. Biofortified staple crops, when consumed regularly, have been reported as generating measurable improvements in human health and nutrition (Bouis and Saltzman 2017). The CGIAR-led “Harvest-plus” program, later morphed into the Agriculture for Nutrition and Health Programme, made significant investments in biofortification of some major staple crops (Anderson *et al.* 2017). Examples include iron-rich crops, vitamin A-rich crops, and zinc-rich crops. One major limitation of biofortification in improving nutrition and health is that it addresses only one or two micronutrients per crop, which is helpful, but not compensatory to the general decrease in nutritional density of modern varieties of staple crops.

Within a TEEBAgriFood Framework, we would posit that diversification of production (and hence the potential for diversification of diet) is a more community-centred approach to improving dietary potential than industrial agriculture offers, and one that promotes exposure to a broad mix of nutrients and non-nutritive organic compounds which have antioxidant, anti-cancer and other beneficial properties (Fanzo *et al.* 2013). In recent years, there has been increasing evidence of the nutritional benefits of diversification of production systems. A study using data from household surveys, after controlling for household characteristics, to estimate the effects of crop diversification on nutrition (dietary diversity) and on income (crops sold) of rural households from eight developing and transition economies has shown a positive correlation between the number of crops cultivated, household income from crops, and two indicators for dietary diversity (Pellegrini and Tasciotti 2014). Similarly, a study surveying farm households in India identified a causal link between dietary diversity and farm-level diversification (Chatterjee 2016), and crop diversification was found to positively influence dietary diversification in Zimbabwe (Chinnadurai *et al.* 2016). It has been argued that diversification of production systems and the market supply of this enhanced diversity will only happen in the developing world when the current distortions to farm- and market-level incentives are corrected (Pingali 2015) and policies supporting diversification are implemented. Unfortunately, investments in greater use of agricultural biodiversity have been insignificant in comparison to investments in biofortification (Toledo and Burlingame 2006).

Another area of increasing interest in terms of moving away from industrial agriculture is that of urban agriculture. Urban agriculture has evolved irregularly over time, with significant increases in periods of crisis, such as during and immediately after World War II, but decreases in periods of relative peace. In the last few decades the growing problem of food insecurity in cities, especially in the wake of the 2007-08 food price spike, has meant the development of many new initiatives supporting urban agriculture.

There is still no consensus on the precise definition of urban and peri-urban agriculture, but it can be defined broadly as the growing of plants and the raising of animals for food within and around cities. It typically uses urban resources (such as organic waste as compost and urban wastewater for irrigation), urban residents as labourers, and has a direct link with urban consumers. It directly impacts urban ecology, in part through competition for land with other urban functions. It is greatly influenced by urban policies and plans (Chinnadurai *et al.* 2016). The activities may take place on the homestead (on-plot) or on land away from the residence (off-plot), on private land (owned, leased) or on public land (parks, conservation areas, along roads, streams, and railways), or semi-public land (schoolyards, hospital grounds).

There are a number of ways through which urban agriculture can, in principle, have an impact on urban food security. At the household level, urban agriculture can be a source of income, can provide direct access to a larger number of nutritionally rich foods (vegetables, fruit, meat) and a more varied diet, can increase the stability of household food consumption by providing a bulwark against seasonality or other temporary shortages (Zezza and Tasciotti 2010). The motivations for engaging in urban agriculture are often quite different in the global north and developing countries. Heynen *et al.* (2012) describe urban agriculture in North America as “a deliberately political action and a way to reclaim spaces that have become dominated through the interests of capital and other corrupting social power relations”. In the U.S., urban gardening also has been suggested as an effective tool for enhancing social cohesion and bridging racial divides by bringing people from different ages, races, and income levels together (Shinew *et al.* 2004; Blaine *et al.* 2010). In the sub-Saharan African context, attention to urban agriculture tends to stress the practice’s potential as a food security or poverty alleviation strategy (Battersby 2013).

Urban agriculture has become a key component of food and nutrition strategies for the poorer segments of the urban population. A large percentage of the people involved in urban agriculture are the urban poor. In sub-Saharan Africa, for example, it is estimated that 40 per cent of the urban population is engaged in agriculture (Reed 2014), while in Vietnam, it can be as high as 70 per cent (Zezza and Tasciotti 2010; Orsini *et al.* 2013). Women constitute an important percentage of urban farmers (Musiimenta 2002; Hovorka *et al.* 2009), since agriculture and related processing and selling activities, among others, can often be more easily combined with their other tasks in the household (Resource Centres on Urban Agriculture and Food Security Foundation 2009).

Some reports estimate that 800 million people worldwide are engaged in urban agriculture, with between 100 and 200 million producing for the market (FAO 1996; Armar-

Klemesu 2000). However, at the global level, there are still no reliable quantitative data on the total number of people involved in urban agriculture or on its contribution to urban food security. A recent study estimates that urban agriculture contributes 100-180 million metric tons of food per year (Clinton *et al.* 2018). It seems clear, however, that in some cities urban agriculture is an important coping strategy for households and makes a significant contribution to improving food security. Self-grown food can contribute to household food security both through direct provisioning and through the sale of produce on the market, generating cash that can be used to purchase food – more so in Latin America than in Africa (Ellis and Sumberg 1998; Maxwell 2003).

Simply put, urban agriculture plays many roles beyond food provisioning (WinklerPrins 2017). In many cases, the quantity of food produced is secondary to community aspects of the endeavour. Still, the global and regional extent of urban agriculture needs to be quantified far more rigorously (Hamilton *et al.* 2014), something a food system approach is much more capable of tackling than more narrow approaches on productivity or supply chains. The current trends of urban agriculture across the developed world indicate that the practice is growing and evolving as crises emerge and fade (Mok *et al.* 2014). Although easier access to safe and nutritious food (mainly fresh products) helps improve health conditions of the urban poor, Orsini *et al.* (2013) have listed a set of potential health concerns related to urban agriculture:

- Contamination by pathogens that results from: i) irrigation with polluted water, ii) inappropriate use of organic fertilizer (e.g. fresh animal and human waste or non-composted urban wastes that are in direct contact with edible parts of the plants), and iii) poor hygienic practices during post-harvest and handling activities (transport, transformation and marketing)
- Contamination as a consequence of inappropriate use of pesticides and difficulty disposing of obsolete or expired stocks
- Contamination of soil and products with heavy metals as a consequence of agricultural production along roads with high traffic or near industrial discharges
- Disease transmission to humans from animal production (bird flu, tapeworm)
- High occurrence of insects/disease vectors (e.g. mosquitoes, for which urban agricultural activities could provide a more water-rich breeding environment) (Klinkenberg *et al.* 2008).

Despite multiple environmental and social benefits to promoting urban agriculture within cities, doing so remains challenging in the face of other urban processes.

Identifying win-win areas for urban farming, where environmental and social benefits can be maximized on otherwise unused land is necessary and possible to build support and acceptance for these urban farming systems both socially and politically (Lin *et al.* 2017).

In the developing world, there are two opposing trends. On the one hand, the pressure of increasing urban populations leads to loss of land in cities and around them where urban agriculture can be practiced. On the other hand, initiatives to support and expand urban agriculture are emerging in many cities of the South making a significant contribution to urban nutrition.

In response to massive population growth, new cities are being planned and built, and existing cities drastically modified, so the opportunity exists for urban agriculture to be included in food systems in an organized rather than an informal manner (Hamilton *et al.* 2014).

4.7 FOOD SYSTEM HEALTH IMPACTS – OCCUPATIONAL HAZARDS, ENVIRONMENTAL CONTAMINATION, AND PATHOGENIC CONTAMINATION

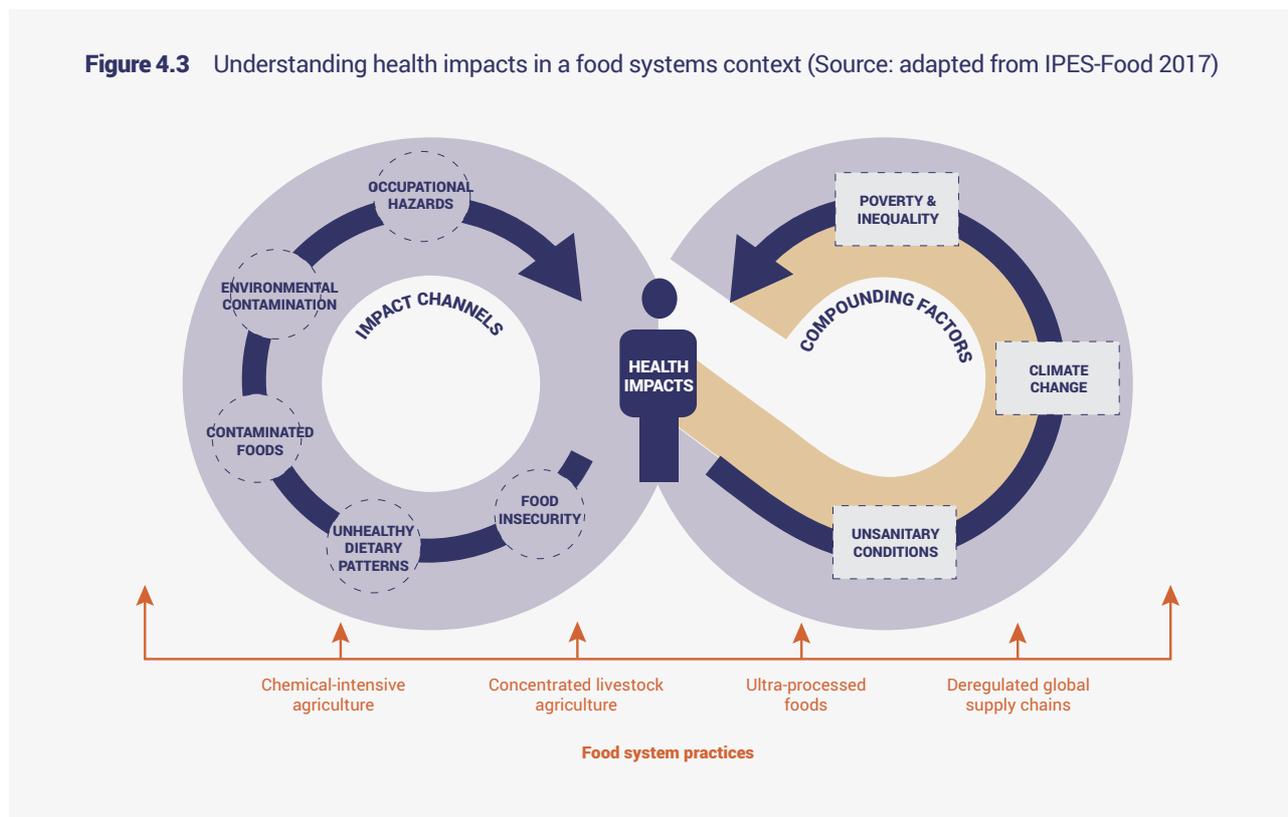
IPES-Food (2017) has identified five key channels through which food systems negatively impact health: occupational hazards; environmental contamination; contaminated, unsafe, and altered foods; unhealthy dietary patterns; and food insecurity – see **Figure 4.3**.

Three of these issues will be explored in this section: occupational hazards, environmental contamination, and pathogenic contamination.

4.7.1 Occupational hazards

The agricultural sector is one of the most hazardous workplaces in which to be employed worldwide (Cole 2006; ILO 2009; The Food Chain Workers' Alliance 2012; IPES-Food 2015). While lack of data is a problem, it is nonetheless known that millions of injuries occur annually to agricultural workers, with at least 170,000 of these resulting in fatalities (Cole 2006). In the U.S., the occupational fatality rate for workers in agriculture, forestry, and fishing from 2006-09 was significantly higher than for all other industries (IoM and NRC 2015).

Figure 4.3 Understanding health impacts in a food systems context (Source: adapted from IPES-Food 2017)



Sites of agricultural production and fisheries have characteristics that jeopardize safety and health: exposure to extreme weather, close contact with animals and plants that could cause injury, extensive use of agro-chemical and biological products, difficult working postures and lengthy hours, and use of hazardous agricultural or fisheries tools and large machinery. These factors have been commonly documented and associated with a range of health conditions from simple heat stress to complex diseases such as cancer. Increased rates of respiratory diseases, skin disorders, certain cancers, poisoning by chemicals, neurological disorders, infertility, and heart-related illnesses have been documented (Rein 1992; Anderson and Bama 2015).

Pesticides are one source of health risk for farmers, agricultural workers and their children; workers on conventional (non-organic) farms are most affected by pesticide exposure due to their constant, long-term contact (Blainey *et al.* 2008). Acute unintentional (accidental) and intentional (suicidal) pesticide poisoning is common (Cole 2006; Eddleston *et al.* 2002; Gunnell *et al.* 2007). Even cases of acute pesticide poisoning are not always recorded by health authorities, though it has been estimated that 2 to 5 million people every year suffer from such acute poisonings (Cole 2006). The number of deaths from accidental pesticide poisoning is unknown – while many have put the number at 200,000 this is likely inaccurate since statistics for pesticide-related toxicity are not well captured (NIOSH 2011; Geiser and Rosenberg 2006).

The overall incidence of poisoning events in the U.S. was reported as 53.6/100,000 farm workers compared to 1.38/100,000 for non-farm workers (Calvert *et al.* 2008). About one-third of the affected workers were pesticide handlers; the rest were farm workers exposed to off-target drift of pesticide applications or exposed to treated plant or animal material. In developing countries, which account for only 25 per cent of pesticide usage, incidents often occur during application in the field because protective clothing is too expensive, damaged or cumbersome and uncomfortable in hot climates (Eddleston *et al.* 2002). In addition, safety precautions may not be understood because of language barriers, illiteracy, or a misinterpretation of pictograms (PAN-Germany 2012). Incorrect handling, storage at home, and disposal of pesticide containers are further risk factors (Konradsen *et al.* 2003). In many parts of Asia and Latin America, pesticide consumption is also a frequently used means of suicide due to the substances' easy availability and lethality (Gunnell *et al.* 2007).

Although still contested by some, evidence shows that lower-dose, chronic exposure to many pesticides is linked to many long-term health effects, even when using correct safety procedures (Human Rights Council 2017). Endocrine disruptor chemicals (EDCs) in pesticides can cause detrimental and transgenerational effects to the embryonic development of the fetus during pregnancy, leading to: both birth defects and developmental disorders; an increased risk of various types of cancer; disruption of the endocrine system, which includes interference

of the body's production, release, and elimination of natural hormones as well as damaging effects to the immune system; neurological problems and cognitive disability; and respiratory distress (Blainey *et al.* 2008; Gilden *et al.* 2010). The direct link between pesticides and some of these conditions is contested because of insufficient funding for research, a sufficiently long lag between exposure and illness making causality difficult to demonstrate, and synergisms among chemicals can be difficult to analyze.

Injury is also common on farms, fishing vessels, and in industrial food production and processing operations (Goldcamp *et al.* 2004; Lindsay *et al.* 2004; McCurdy *et al.* 2004; Carlson *et al.* 2005; Jones and Bleeker 2005; Pickett *et al.* 2005; Cole *et al.* 2006; Marlenga *et al.* 2006; Solomon *et al.* 2007; Sosnowska and Kostka 2007). The most frequent injuries included sprains, strains, broken bones, crushes, hearing loss from operating noisy machines and engines. Truck drivers, many of whom transport food items, suffer high fatality rates (Forkenbrock 1999). High rates of injuries are also reported for concentrated animal feeding operations (CAFOs) (Mitloehner and Calvo 2008). The high-pressure work environments of industrialized food processing plants, where work is performed over long periods of time at a fast pace, and in extreme environments (such as refrigeration rooms), put workers at an increased risk for frequent injury (Chiang *et al.* 1993; Kaminski *et al.* 1997; Campbell 1999; Grzywacz *et al.* 2007; Lloyd and James 2008; Sormunen *et al.* 2009; The Food Chain Workers' Alliance 2012). Back injuries, slips and falls, and motor vehicle-related accidents are frequent with warehouse workers (Harrington 2006).

Occupational conditions for farm workers are often minimally regulated (Graham *et al.* 2008). Migrant workers are disproportionately affected because they tend to be given more manual, strenuous and repetitive tasks, required to perform intense physical labour (Arcury and Quandt 2007; Anthony *et al.* 2008), and put in situations with hazardous equipment (knives, machetes, etc.) with little safety training or supervision (Cole 2006). Language, cultural, and legal barriers also may impede them from seeking medical attention, which may lead to more protracted injuries (Otero and Preibisch 2010).

4.7.2 Environmental contamination

Air and water pollution caused by agricultural and food processing activities are the main pathways for the food system to cause negative human health impacts. Anthropogenic inputs such as fertilizers, pesticides, and chemicals, along with waste products from agricultural and industrial activities – including wastewater, irrigation runoff, manure and animal waste – leach into the environment and affect people's health (IPES-Food 2016).

Agriculture is the second leading cause of outdoor air pollution globally after emissions from residential energy use (Lelieveld *et al.* 2015). In many regions of the world agriculture is reported to be the largest contributor – with up to 40 per cent of air pollution in several European countries reported (*ibid.*). On a global scale, outdoor air pollution leads to 3.3 million premature deaths annually (*ibid.*). In particular, pollution with airborne particulate matter that is smaller than 2.5 micrometres in diameter (PM_{2.5}) (Bauer *et al.* 2016) at high levels can cause acute lower respiratory illness, cerebrovascular disease, ischaemic heart disease, chronic obstructive pulmonary disease, and lung cancer (Lelieveld *et al.* 2015). Agricultural production is a key producer of PM_{2.5} matter. While air pollution affects all residents since airborne particulate matter may drift between regions and even from one country to another, it is at the intersection of intense agricultural production and large population centres (with concentrated industrial production and transport systems) that the chemical process of PM_{2.5} formation is most powerful. Indeed, in China, the 10 cities that registered the highest PM_{2.5} levels in 2013 were all surrounded by intensive agriculture (Gu *et al.* 2014).

Livestock production and fertilizer use are key culprits in air pollution, particularly, livestock production close to urban areas, which facilitates the mixing of SO₂ and NO_x emitted from fossil fuel combustion with agricultural NH₃, resulting in high levels of air pollution in cities (Gu *et al.* 2014; Paulot and Jacob 2014). Residents living near CAFOs are reported to have increased incidence of respiratory distress, digestive disorders, anxiety, depression, and sleep disorders. Children living on farms raising swine were reported to have a higher incidence of asthma, with increasing incidence as the size of the swine operation increased.

Policy changes to lower the maximum amount of permissive ammonia output may be instrumental in protecting public health from anthropogenic air pollution (Vieno *et al.* 2016). Long-term reductions in particulate matter in the atmosphere have been related to increased life expectancy (Pope *et al.* 2009). To achieve this, adjusting feed compositions for stock animals (to a diet with less protein, which leads to less excess nitrogen) and improving housing conditions for livestock operations also have emerged as key imperatives (Aldern 2015). Covering manure tanks, and using more careful application procedures of fertilizers, slurries, and manures can help decrease gaseous losses of nitrogen through ammonia emissions (Gu *et al.* 2014; Jokela *et al.* 2012).

Other forms of environmental pollution include persistent organic pollutants (POPs) such as dioxins and polychlorinated biphenyls (PCBs) have become widespread environmental contaminants (Fisher 1999). Their toxicity in humans and wildlife is enhanced by their

persistence in the environment and their bioaccumulation potential through the food chain (ibid.). POPs include a variety of man-made chemicals including polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), PCBs, hexachlorobenzene (HCB), and several organochlorines used as pesticides whose use has been highlighted by international organizations as a health concern (Abelsohn *et al.* 2002; Grandjean *et al.* 2008). In addition to reproductive and developmental effects, many POPs are known or suspected carcinogens (Jones and de Voogt 1999; Ashraf 2017) and low-level exposure to some POPs has recently been associated with an increased risk of diabetes (Lee *et al.* 2006; Taylor *et al.* 2013).

Many significant health issues also have been associated with endocrine disrupting chemicals (EDCs), or endocrine disruptors (EDs), ubiquitous in our modern food systems due to pesticides used in conventionally grown crops as well as from hormones used in meat production, poultry, and dairy products. Chemicals used to coat food cans and in some plastic containers, compounds used as food preservatives, and even substances in non-stick cookware are all reported to be EDCs (Wielogorska *et al.* 2015). There are close to 800 chemicals known or suspected to function as EDCs (WHO and UNEP 2013).

EDCs in lab studies on in vitro cells have been associated with many female reproductive disorders, including cancers (Crain *et al.* 2008; Roy *et al.* 2009), urogenital tract malformation (Fernandez and Olea 2012), testicular cancer (Chia *et al.* 2010), and decreases in semen quality and sperm count (Li *et al.* 2011). Laboratory studies with animals also have associated EDCs with the development of diabetes and obesity (Newbold 2010; Thayer *et al.* 2012). The annual health costs of exposure to EDCs in the EU has been estimated at €163 billion/US\$217 billion (a per capita cost of €428) (Trasande *et al.* 2016), while in the United States, the cost is estimated to be \$340 billion, or 2.33 per cent of GDP (Attina *et al.* 2016) – see **Figure 4.4**.

The consequences of long-term exposure to pesticide residues in food are still poorly documented. This is particularly important in countries that have poor or no

pesticide residue control measures in place (Lehmann *et al.* 2017). Yet it is also important in countries with stronger control measures. For example, a recent case in Europe of contamination of eggs by fipronil, a possible carcinogenic pesticide, has caused significant concerns (Boffey 2017; Food Standards Agency 2017). There is increasing need to address the potential risks of combined exposures to multiple residues from pesticides in the diet (Kortenkamp 2014). Emerging evidence shows that soil pollution and other types of environmental contamination pose appreciable health risks. Ammonia (NH₃) pollution from agriculture has been considered a major cause of health damage in the U.S. (Paulot and Jacob 2014).

Water pollution is another significant challenge to health in our current food system. Nitrate and phosphorus pollution due to excessive chemical fertilizer use and feedlot runoff leaches into the groundwater system, through rain and soil seepage, carrying with it nitrogen, phosphorus, other chemicals, as well as multiple disease-carrying pathogens, such as *E. coli* (Anderson and Sobsey 2006; Dan-Hassan *et al.* 2012), leading to contaminated environments. Low-income agricultural communities in developing countries without access to potable water are most vulnerable to water pollution related health impacts. However, even in developed countries, increasing levels of agrochemical and nitrate pollution in public water sources makes it difficult for suppliers of drinking water to provide water below the maximum concentration of nitrate mandated by law (Ward 2009; PAN - North America 2012; Espejo-Herrera *et al.* 2016; Iowa Environmental Council 2016). High levels of nitrate in drinking water have been associated with spontaneous abortions (Tabacova *et al.* 1998; Guillette and Edwards 2005; Espejo-Herrera *et al.* 2016), birth defects including congenital anomalies, neural tube defects, methemoglobinemia, or blue-baby syndrome, a potentially life-threatening condition that decreases the blood's ability to distribute oxygen in the body (Gupta *et al.* 2008), and several types of cancer such as bladder cancer, thyroid cancer, and non-Hodgkin's lymphoma (Iowa Environmental Council 2016; Nolan *et al.* 2002).

Figure 4.4 Annual costs resulting from endocrine-disrupting chemical (EDC) exposure (Source: adapted from Attina *et al.* 2016; Trasande *et al.* 2016)

\$217
BILLION

EU - 1.28% of GDP

\$340
BILLION

USA - 2.33% of GDP

\$42
BILLION

USA - Pesticides alone

The use of wastewater for irrigation in China, particularly in regions with concentrated mining and smelting activities, has resulted in dangerous levels of heavy metals in water sources and soils, while intensive livestock production has led to increased concentrations of zinc, arsenic and copper (Lu *et al.* 2015). The convergence of industrial activities and wastewater irrigation also has caused heavy metal pollution in other parts of the world (Luengo-Fernandez *et al.* 2013).

4.7.3 Pathogenic contamination

Another key element of environmental contamination from livestock concerns the spread of bacteria (including those with developed resistance to antimicrobials), e.g. bacteria from animal feces used as a fertilizer and remaining on crops, wind-blown transmission of dust from livestock operations, and bacteria from animal feces that enters into the water system (Centers for Disease Control and Prevention 2013; McEachran *et al.* 2015).

The threat of zoonoses – communicable human diseases originating in or carried by animal populations – is of concern relative to existing and emerging pathogenic risks (Newell *et al.* 2010; Slingenbergh *et al.* 2004; WHO 2013). Indeed, 75 per cent of emerging diseases and 63 per cent of current pathogen species are zoonotic in origin (Jones *et al.* 2013). New zoonotic infectious diseases emerge most frequently in areas where the natural habitat and wild animal populations overlap with the human habitats and landscapes devoted to domesticated animals (Leibler *et al.* 2009; Patz *et al.* 2004). Different forms of animal farming expose workers to different zoonotic diseases. For example, animal handlers working with dairy cows and sheep are at high risk from *Brucellosis* in endemic areas of Central Asia, Africa, and Latin America (Corbel *et al.* 2006), while herders in Africa are at higher risk from Rift Valley Fever (Anyangu *et al.* 2010).

Intensified, large-scale production and processing of livestock such as pigs and chicken have seen rapid increases in scale globally – particularly in low- and middle-income countries with relatively weak veterinary and public health infrastructure (Graham *et al.* 2008; Liverani *et al.* 2014). Combined with the pressures of urbanisation, the growing demand for animal products exacerbates competition for land and resources. Humans and domestic animals are more exposed to wildlife and the diseases they carry as food production encroaches onto wild ecosystems, often via deforestation, (Morse 2004; Patz *et al.* 2004; Goodwin *et al.* 2012).

Adverse health impacts from intensified production practices have been attributed in particular to industrial animal production facilities, such as feedlots and CAFOs where intensive production practices create a large number of interconnected amplification pathways for viral, bacterial, and parasitic pathogens. Livestock

intensification allows for the introduction of pathogens into concentrated production units, where these disease agents adapt and reproduce at a rapid pace (Liverani *et al.* 2014; Slingenbergh *et al.* 2004). Workers also suffer microbial infections from working in processing plants. While the food-borne transmission route is the most common infection pathway in developed countries, Hale *et al.* (2012) show in the U.S. that up to 14 per cent of the enteric disease burden of seven major zoonotic pathogens can be attributed to direct animal contact.

In industrial livestock systems and fish farms, farmers frequently turn to antibiotics not only to treat sick animals, but also to prevent the outbreak of illnesses and accelerate the growth process of meat animals (Collignon *et al.* 2005). Globally, more antibiotics are used preventively in livestock operations than to treat human diseases (WHO 2012; CDC 2013; Ahmed and Shimamoto 2015; Laxminarayan *et al.* 2016; Spellberg *et al.* 2016). Many of the antibiotics used on animal agriculture and aquaculture are the same antibiotics as in human medicine (Cabello 2006; Done *et al.* 2015), leading to dangerous decreases in efficacy, since bacteria regularly exposed to an antibiotic can become resistant. The administration of low doses – common in preventative health or growth stimulation contexts – may kill most, but not all, bacteria in a particular population. Bacterial strains with minor mutations that remained unaffected by the antibiotic will then survive and reproduce rapidly, self-selecting for greater antibiotic resistance (Chang *et al.* 2015). Even production systems not using antibiotics directly can be vulnerable to contamination, such as through cross-use of manure. For example, a U.S. study found multidrug resistant (MDR) bacteria in all the samples of conventional retail chicken meat as well as in the majority of organic meat samples (Cohen Stuart *et al.* 2012). There is also the problem of antibiotic resistance that is transmitted directly from animals to their handlers, with many farm operators and workers having shown signs of antibiotic resistance (Price *et al.* 2007; Zhang *et al.* 2009; Meena *et al.* 2015).

Fungal mycotoxins are another result of crop and food pathogenic contamination. These are secondary metabolites produced by fungi that colonize food crops (Wu *et al.* 2013), mainly belonging to the *Aspergillus*, *Penicillium*, and *Fusarium* genera. Some 300 compounds have been recognized as mycotoxins, of which around 30 are considered a threat to human or animal health. Mycotoxin exposure via food and feed may result in carcinogenicity, immunotoxicity, reproductive toxicity, hepatotoxicity, nephrotoxicity, etc. (Bennett and Klich 2003). Global surveys indicate that more than 70 per cent of the samples of feed and feed raw materials tested are positive for at least one mycotoxin (Streit *et al.* 2013). Exposure to aflatoxin can lead to the development of one of the deadliest cancers worldwide – liver cancer. Aflatoxin is responsible for up to 172,000 liver cancer cases per

year (Wu *et al.* 2013; Wu 2015). Maize contaminated with aflatoxins has been implicated in deadly epidemics of acute aflatoxicosis in Kenya, India, and other countries (Lewis *et al.* 2005).

Individuals' health can also be compromised by the ingestion of contaminated foods. Food-borne disease agents fall into distinct categories – most importantly bacteria, viruses, and parasites – and can cause a variety of illnesses upon ingestion (Newell *et al.* 2010). Food containing harmful bacteria, viruses, parasites, or chemical substances cause more than 200 diseases, ranging from diarrhoea to cancer (WHO 2015b). While foodborne pathogens can cause severe diarrhoea or debilitating infections, food chemical contamination can lead to acute poisoning or long-term diseases, such as cancer. An estimated 600 million people – 1 in 12 people in the world – get ill from consuming contaminated food, and 420,000 die each year, resulting in the loss of 33 million disability-adjusted life years (DALYs) (WHO 2015b). Foodborne diseases impede socioeconomic development by straining healthcare systems as well as harming national economies, tourism, and trade.

The emergence of prions, infectious agents composed entirely of protein, such as the agent of bovine spongiform encephalopathy (the cause of variant Creutzfeldt-Jakob Disease in humans) has been associated with intensive animal production systems. Parasitological diseases such as cysticercosis, echinococcosis, and trichinellosis are related to traditional animal rearing methods, unregulated slaughtering, and consumption of animal products. Aquatic foodborne trematode infections affect more than 40 million people per year worldwide, over half in Southeast Asia and the Western Pacific (WHO Regional Office for the Western Pacific 2004). Research in the U.S. has attributed 46 per cent of foodborne illnesses recorded between 1998 and 2008 to produce infected by parasites, particularly *E. coli* and norovirus.

4.8 DIETARY PATTERNS AND FOOD INSUFFICIENCY

4.8.1 Dietary patterns

Besides impacts from exposure or contamination by pesticides, food additives, and hormones, dietary patterns of either over- or undernutrition can also negatively affect human health. Diets greatly influence risk factors for both chronic and acute disease, especially cardiovascular diseases, diabetes and some cancers. The leading metabolic risk factors for these diseases include overweight/obesity, hypertension, elevated blood glucose, and high cholesterol (WHO 2014a).

The worldwide prevalence of obesity more than doubled between 1980 and 2014. In 2014, more than 1.9 billion adults age 18 and older were overweight, of which over 600 million were obese. In 2014, an estimated 41 million children under the age of 5 were overweight or obese (GBD 2015 Mortality and Causes of Death Collaborators 2016; UN Children's Fund, WHO and World Bank 2017). The prevalence of overweight and obesity is rising in every region and nearly every country, including in both urban and rural areas in sub-Saharan Africa and in South Asia's poorest countries (Popkin *et al.* 2012). Among lower GDP countries, urban women are more likely than urban men to be overweight/obese. The number of children younger than 5 who are overweight is approaching the number who suffer from wasting (IFPR 2016). The fetal origins hypothesis predicts that prenatal undernutrition could increase the propensity for obesity later in life (Barker and Osmond 1986; Adair and Prentice 2004; Almond and Currie 2011). Being overweight or obese increases the risk for cancers of the oesophagus (adenocarcinoma), colorectum, breast (postmenopausal), endometrium and kidney (Key *et al.* 2004; Reilly and Kelly 2011; Park *et al.* 2012). The problem of obesity is now a staggering and multi-dimensional global challenge.

Calories obtained from meat, oils, fats, sugars, and other refined carbohydrates have increased during past decades, and those from fibre-rich foods (whole grains, legumes, roots) have declined. The overall proportion of processed and highly processed food in diets has grown and is rising rapidly in low- and middle-income countries. In those countries, there has been a shift toward more Western diets, with increased reliance upon processed foods and greater use of edible oils and sugar-sweetened beverages (Popkin *et al.* 2012). Dietary patterns also are changing toward the consumption of more foods of animal origin. If trends continue, global demand for beef is projected to increase by 95 per cent, and animal-based foods in general by 80 per cent, between 2006 and 2050 (Ranganathan *et al.* 2016). These changes in dietary patterns – coupled with globalization, urbanisation, changes in lifestyle, and low physical activity – have been termed the "nutrition transition" (Wessells and Brown 2012). Such changes can lead to rapid increases in obesity and chronic diseases, even among the poor in developing countries (Popkin *et al.* 2012).

This is problematic for a number of reasons. First, fruits and vegetables have the potential to reduce calorie consumption through displacement of high-calorie processed foods. Furthermore, fruits and vegetables contribute to preventing cardiovascular disease and are protective against some cancers. Eating low-calorie foods (such as fruits and vegetables, which tend to be about 0.7-1.5 cal/g) in place of high-calorie foods (4-9 cal/g), appears to mitigate weight gain and help with its management (CDC 2005) in part due to the increased satiety of these lower calorie foods (Manitz *et al.* 2014) that have high volume and high water and fibre content (Popkin *et al.* 2012). Fruits and

vegetables also contain a wide array of compounds that, although not nutrients in the classical sense, nonetheless may play an ancillary role in disease prevention and wellness. Cruciferous vegetables – including kale, collards, radishes, and broccoli – contain glucosinolates, a group of compounds thought to be cancer preventing (NIH 2012). Cooking and chewing them results in breakdown products such as indoles and isothiocyanates, which are felt to be chemopreventive in a variety of organs – for example, lung cancer (Rolls *et al.* 2004).

In general, the evidence to date are still mixed on the overall impact of increased fruit and vegetable consumption, at least in healthy populations, on cancer risk reduction (Key 2011). However, a new study from the Netherlands (Aune *et al.* 2017) indicates that consumption of 800 gm/d of fruits and vegetables (eight servings) reduces the risk of cardiovascular disease, cancer, and all causes of mortality. As the authors state, “an estimated 5.6 and 7.8 million premature deaths worldwide in 2013 may be attributable to a fruit and vegetable intake below 500 and 800 g/day, respectively, if the observed associations are causal.”

Data from a large number of recent studies points to a reduction of red meat to help reduce the risk of cardiovascular disease (Willett 2012; Satija *et al.* 2017). Cured meat and red meat are likely to increase the risk for colorectal cancer, while preserved foods and high salt intake appear to increase the risk for stomach cancer (Key *et al.* 2004; Potter 2017). A 10 per cent increase in ultra-processed food intake has been associated with a 10 per cent increase of cancer risk (Fiolet *et al.* 2018). Chinese-style salted fish increases the risk for nasopharyngeal cancer, particularly if eaten during childhood.

Lifestyle factors, including diet, play an important role in the aetiology of cardiovascular disease (CVD). The most important behavioural risk factors for heart disease and stroke are unhealthy diet, physical inactivity, tobacco use, and harmful use of alcohol (WHO 2018a). The effects of behavioural risk factors may present in individuals as elevated blood pressure, elevated blood glucose, elevated blood lipids, and overweight/obesity. These, in turn, are indicative of an increased risk for heart attack, stroke, and heart failure.

Elevated weight (obesity/overweight) coupled with a lack of fitness is a major risk factor for NCDs such as cardiovascular diseases (mainly heart disease and stroke), diabetes, musculoskeletal disorders (especially osteoarthritis – a highly disabling degenerative disease of the joints), and some cancers (including endometrial, breast, ovarian, prostate, liver, gallbladder, kidney, and colon (WHO 2014a; WHO 2016b)) through inadequate intake of fruits, vegetables, nuts, seeds, and dietary fibre, and high consumption of red and processed meat (Lim *et al.* 2012; Sabate and Soret 2014).

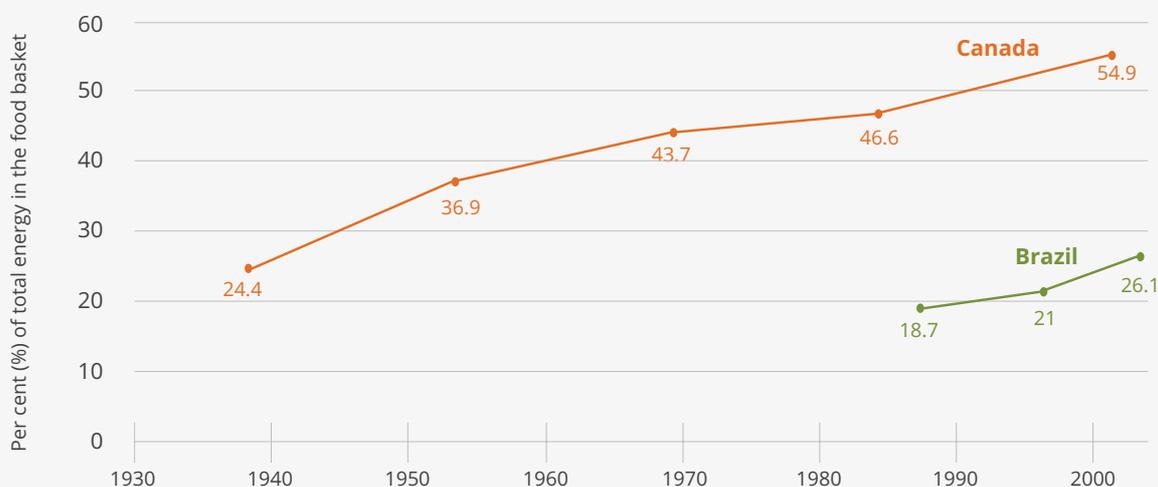
The relation between dietary patterns and human health is well established. Diets high in vegetables, fruits, whole grains, pulses, nuts, and seeds, with modest amounts of meat and dairy, promote health and well-being (DGAC 2015).

Generally, dietary recommendations across the globe include calls to increase the consumption of whole vs. refined grains. WHO (2015a) recommends whole grains as part of a healthy diet. The Whole Grains Council cites steady increases in the number of whole grain products available and the number of products re-formulated to increase the whole grain content (Aune *et al.* 2017). A meta-analysis demonstrated an inverse association between whole grain consumption globally, and type-2 diabetes risk (Aune *et al.* 2013).

Another consideration in our dietary patterns is the widespread introduction of ultra-processed foods. Ultra-processed products are ready-to-consume, entirely or mostly made from industrial ingredients and additives. They are typically energy-dense, have a high glycaemic load, are low in dietary fibre and micronutrients, and high in unhealthy types of dietary fat, free sugars, and sodium. Monteiro *et al.* (2013) have examined the growth in consumption of these products with a focus on Canada and Brazil, reporting a steady increase, such that ultra-processed products now comprise 54.9 and 26.1 per cent of total energy consumption, respectively (as of 2005) (see **Figure 4.5**). Across 79 high- and middle-income countries, the growth rate was highest from 1998-2012 among the lowest income countries studied, with growth rate slowing as per capita income increased. Monteiro *et al.* (2011) reported that increases in ultra-processed foods are largely at the expense of unprocessed foods and processed culinary ingredients, with an overall nutrient dietary profile that had more sugar, more fat, more sodium, less fibre, and higher energy density. A New Zealand study reported that, in supermarkets, the majority of processed foods were ultra-processed and had a far worse nutrient profile than culinary processed foods (Luiten *et al.* 2016). Baker and Friel (2016) examined food systems transformations in Asia and reported significant increases in ultra-processed foods – especially soft drinks.

Diet is a central lifestyle component that plays an important role in the aetiology of cardiovascular disease (CVD). Other behavioural risk factors for heart disease and stroke are physical inactivity, tobacco use, and harmful use of alcohol (WHO 2018a). The effects may manifest in individuals as elevated blood pressure, elevated blood glucose, elevated blood lipids, and overweight/obesity. These, in turn, are indicative of an increased risk for heart attack, stroke, and heart failure.

Figure 4.5 Time changes in the dietary share of ultra-processed products in the average household food basket in Canada and Brazil (Source: adapted from Monteiro *et al.* 2013)



Obesity results from a number of causes, including genetic background and endocrine disrupting chemicals widespread in our food supply (Gore *et al.* 2015). Yet, the most common proximate cause is an energy imbalance – the difference between calories consumed and calories expended (Wright and Aronne 2012). Changes in dietary and physical activity patterns are often the result of environmental and societal changes associated with development. Economic development across nations typically lacks supportive policies in sectors such as health, agriculture, transport, urban planning, environment, food processing, distribution, marketing, and education to minimize this caloric imbalance (Hawkes 2017). It has been hypothesized that continuous low-dose exposure to antibiotics in the meat supply, via gut biota modification, may influence obesity development (Riley *et al.* 2013).

Supermarkets and grocery stores are often the retail conduit for such foods and will play an increasingly important role in nutrition transitions. Access to technologies (e.g. processing, modern supermarkets, and food distribution and marketing), regulatory environments (e.g. the World Trade Organization [WTO]), and freer flow (e.g. of goods, services, and technologies) are contributing to and co-evolving with often rapidly changing diets in low- and middle-income countries. Many groups focus on overall food supply, while the overall transition has shifted the structure of prices and food availability in significant ways.

The makeup of a diversified, balanced, and healthy diet will vary depending on individual needs (e.g. age, gender, lifestyle, degree of physical activity), cultural context, locally available foods, and dietary customs. Diets high in

vegetables, fruits, whole grains, pulses, nuts, and seeds, with modest amounts of meat and dairy, have been shown to promote health and well-being (DGAC 2015). Basic principles of what constitutes a healthy diet according to the WHO are included in **Box 4.1**.

FAO and WHO promoted the concept of Food-Based Dietary Guidelines (FBDG) following the 1992 International Conference on Nutrition. To date, only 83 countries (out of 215) have adopted dietary guidelines (Gonzalez Fischer and Garnett 2016). Dietary guidelines are particularly absent in low-income countries (e.g. only five countries in Africa have guidelines).

Several countries, such as the Nordic countries (Nordon 2014), Brazil (Ministry of Health of Brazil 2014), and the U.S. (DGAC 2015), have been providing evidence of the need to address sustainability in their FBDG. In general, the sustainable dietary guidance from these countries focuses on decreasing meat consumption, choosing seafood from non-threatened stocks, eating more plants and plant-based products, reducing energy intake, and reducing food waste. The Brazilian FBDG also address social and economic aspects of sustainability. The draft report of the U.S. FBDG at the time also addressed environmental sustainability and long-term food security – although environmental sustainability was eliminated in the final guidelines due to political pressure.

Box 4.1 A healthy diet for adults

- Fruits, vegetables, legumes (e.g. lentils, beans), nuts, and whole grains (e.g. unprocessed maize, millet, oats, wheat, brown rice).
- At least 400 g (5 portions) of fruits and vegetables a day. This can save 2.7 million lives (WHO, 2008)
- Less than 10 per cent of total energy intake from free sugars, which is equivalent to 50 g (or around 12 level teaspoons) for a person of healthy body weight consuming approximately 2,000 calories per day, but ideally less than 5 per cent of total energy intake for additional health benefits.
- Less than 30 per cent of total energy intake from fats. Unsaturated fats (e.g. found in fish, avocado, nuts, sunflower, canola and olive oils) are preferable to saturated fats (e.g. found in fatty meat, butter, palm and coconut oil, cream, cheese, ghee, and lard). Industrial trans fats (found in processed food, fast food, snack food, fried food, frozen pizza, pies, cookies, margarines) are not part of a healthy diet.
- Less than 5 g of salt (equivalent to approximately 1 teaspoon) per day and use iodized salt.

Source: WHO 2015a

The social ecological model of behaviour indicates that the environment in which people exist plays a defining role in behaviour (Sallis *et al.* 2008; Golden and Earp 2012), and advertising is a key component of today's environment. Attempts to improve national dietary patterns often are confounded by advertising, selected sales, and product placements. Across the globe, such marketing contributes to negative health outcomes. In the U.S., an astounding amount of time and effort is spent encouraging children to request fast-food happy meals and other high-calorie foods (Federal Trade Commission 2008). The same is true across the developed world, such as England (Boseley 2016), Germany (Foodwatch 2015), and Australia (Watson *et al.* 2017). The WHO Regional Office for Europe (2017) has released data collection guidelines for the EU to help monitor meeting the goal of reduced advertising exposure of children. The same trends in junk food consumption are emerging in parts of Africa (Igumbor *et al.* 2012; Okoti 2017) and China (Dasgupta 2016) with alarming consequences for obesity rate increases. As indicated in a recent report, there is a strong correlation between the rate of commercial viewing and junk food consumption (Thomas *et al.* 2018). The ability of advertising to impact food choices – for better and for worse – should be included in any analysis of food system typology trade-offs.

Trade agreements can also strongly influence consumption changes. It is clear that one consequence of the North American Free Trade Agreement (NAFTA) is a big rise in obesity among Mexico's population, with a three-fold increase among women (ages 20-49) between 1988-2006 (Clark *et al.* 2012). In response, Mexico implemented a sugar tax on soft drinks with a demonstrated reduction in consumer purchases (Colchero *et al.* 2016). A WHO (2016c) report outlines a number of recommendations for greatly reducing childhood obesity, the sum total of which argues for

much greater coherence between trade, agricultural, and health policy.

As stated earlier, traditional food systems have some highly processed foods (modern-to-traditional in the abbreviated typology used in this chapter), but the extent of their place in the market is far reduced relative to those with supermarkets as the end point (modern food system typology). This begs the question: when comparing food systems nationally or in a region, does it make sense to examine the manner in which the entire system begins to drive patterns of consumption, leading to changes in acute and chronic disease risk and then internalize those health and well-being costs? With a TEEBAgriFood Framework, this is not only desirable but also absolutely necessary to obtain a more complete picture of agricultural production and its overall implications for health.

4.8.2 Insufficient diets

In many countries the problem of obesity in some populations coexists with insufficient nutrient intakes among others. When it comes to undernutrition, the most prevalent concerns are overall calorie and/or protein deficits, vitamin A/beta-carotene deficiency, iron deficiency, iodine deficiency, and zinc deficiency. Globally, over two billion people suffer from some form of micronutrient malnutrition (IFPRI 2015). About 25 per cent of children globally are stunted, with the number rising to one-third in some developing countries (de Onis *et al.* 2012; Black *et al.* 2008). WHO (2018b) data from 2010 indicates:

- About 104 million children worldwide are underweight
- Undernutrition contributes to about one-third of all child deaths

- Stunting (an indicator of chronic undernutrition) hinders the development of 171 million children under age 5
- 13 million children are born prematurely or with low birth weight due to maternal undernutrition and other factors
- Together, maternal and child undernutrition account for more than 10 per cent of the global burden of disease.

Vitamin A is an essential nutrient, key for proper vision, as well as immune system function. Humans obtain it either as vitamin A (from animal product sources) or in its precursor form – beta-carotene – of which many fruits and vegetables are excellent sources. Getting our daily need does not require a large amount of food. For example, two servings a day of carrots or spinach provides all the vitamin A required for everyone except lactating mothers (NIH 2016). Yet many people, especially young children, get well below their requirements because of a deficit of fruits, vegetables, and animal products in their diet. It is estimated that 190-250 million preschool children and 19 million pregnant/lactating women have sub-optimal intakes (WHO 2009; 2018d), resulting in an estimated 250-500,000 cases of preventable blindness per year. And yet this is, in theory, simple to resolve with or without staple crop bio-fortification.

Anaemia is another common micronutrient deficiency around the world (Stevens *et al.* 2013), affecting about 1.6 billion people globally, with much higher rates in the developing world (43 per cent) compared to the developed world (9 per cent) (McLean *et al.* 2009)

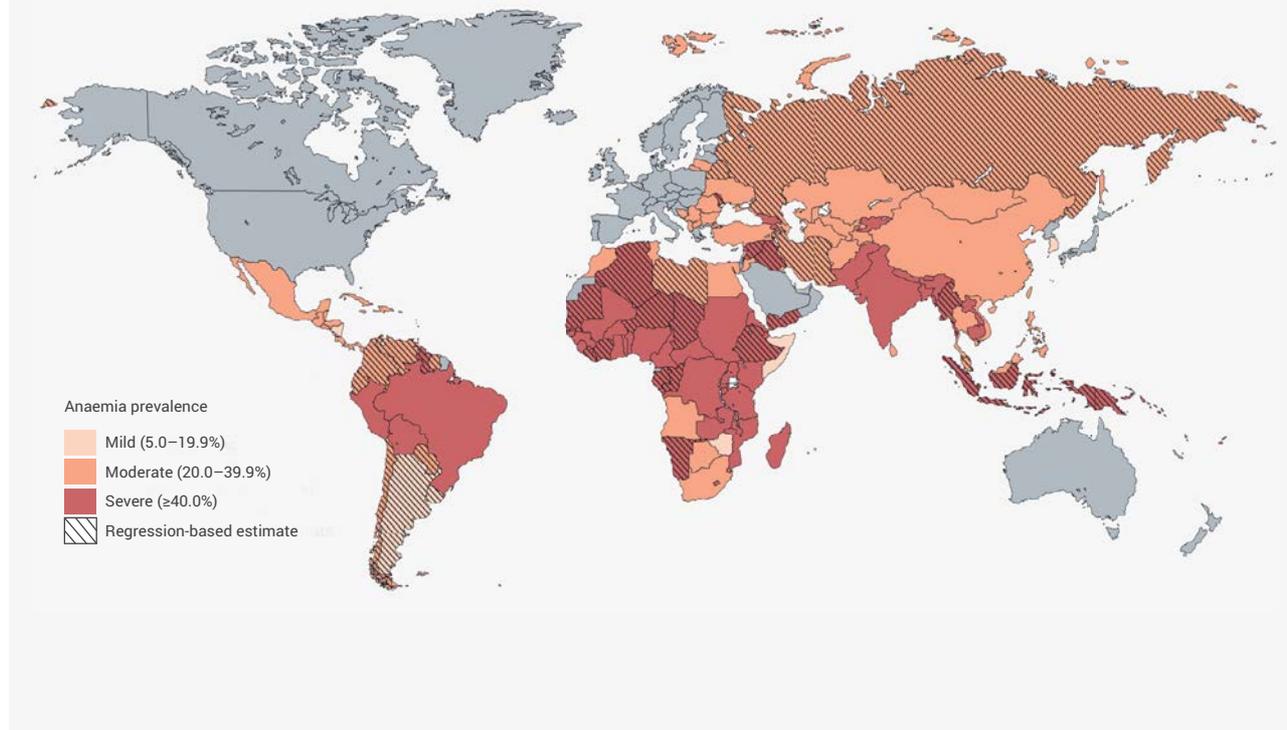
It is particularly prevalent in high risk groups – children younger than 5 (see **Figure 4.6**) and pregnant/ lactating women – with 85 per cent of the total global prevalence among high-risk groups found in Africa and Asia. Overall, the greatest number of anaemia incidences is found in non-pregnant or lactating women – about 468 million (WHO 2008). Anaemia exhibits broad impacts in a community, including increased risk of infection, loss of productivity, cognitive impairment and difficulty learning. While many assume that anaemia is caused by iron deficiency, only about 50 per cent of global burden is due to levels of iron intake – although this number is a broad estimate (Ezzati *et al.* 2004). Three other micronutrients – folic acid, vitamin B12, and vitamin A (Zimmermann *et al.* 2006) – also play a role in erythropoiesis (red blood cell formation). Depending on the area of world and type of diet, these also are implicated for significant portions of the global burden. In addition, a number of parasites, especially hookworm (Bartsch *et al.* 2016) increase the risk of anaemia – via both enhanced blood loss and/or impacts on iron absorbability.

A number of factors affect iron absorption in the intestine: animal-based iron is more absorbable than plant-based (due to phytate binding); sufficient vitamin C increases absorbability of iron due to an intestinal effect; reduced parasitic infection increases iron absorption, among other factors. Vegetarians often have lower B₁₂ levels (necessary for intestinal and red blood cell formation) than omnivores, largely dependent on the degree of vegetarianism and/or the consumption of other B₁₂ containing foods, such as yeast products. In the case of anaemia and diet, having a healthy, balanced diet presents a much better individual profile for limiting the risk of anaemia and attendant deleterious effects. Five strategies can help reduce the incidence and burden of anaemia: access to diverse food sources, clean water and sanitation, fortified foods, health services, and knowledge and education.

Zinc is another element necessary for several health outcomes including normal pregnancy, lactation, neuromuscular development, gonadal development, and growth (Prasad 1991). Zinc deficiency is not as widespread as the lack of some other nutrients, yet it is still a major public health concern. **Figure 4.7** illustrates the estimated rates of zinc deficiency across the globe, determined by the prevalence of zinc in the national food supply. The authors estimate about 17 per cent of the global population is at risk for zinc deficiency, and there was a strong negative correlation between the total calories available in a country and the level of zinc deficiency – as calories available increased, zinc deficiency decreased. Like iron, zinc is more bioavailable from animal products than plant. That said, there are a number of good plant sources of zinc.

It is estimated that about two billion people globally have insufficient intakes of iodine (Zimmermann 2009), with sub-Saharan Africa and Asia particularly affected. Its primary function is the production of thyroid hormone (deficiency producing goitre as a physical/visible manifestation of frank deficiency, with cretinism the most extreme consequence in living offspring). Inadequate levels affect growth, development, and maturation. Iodine deficiency during pregnancy has adverse implications for infant mortality. Unfortunately, the iodine content of most foods is relatively low – with seafood (and seaweed) being a striking exception due to the concentration of iodine found in sea water. Generally, iodization of salt is the most efficient and best strategy for decreasing iodine deficiency (Zimmermann *et al.* 2008) since the level of iodine in plants/ animals is very dependent on soil content levels (true for other minerals as well).

Figure 4.6 Global prevalence of anaemia in children of preschool age 0-5 years (Source: adapted from Balarajan *et al.* 2015)

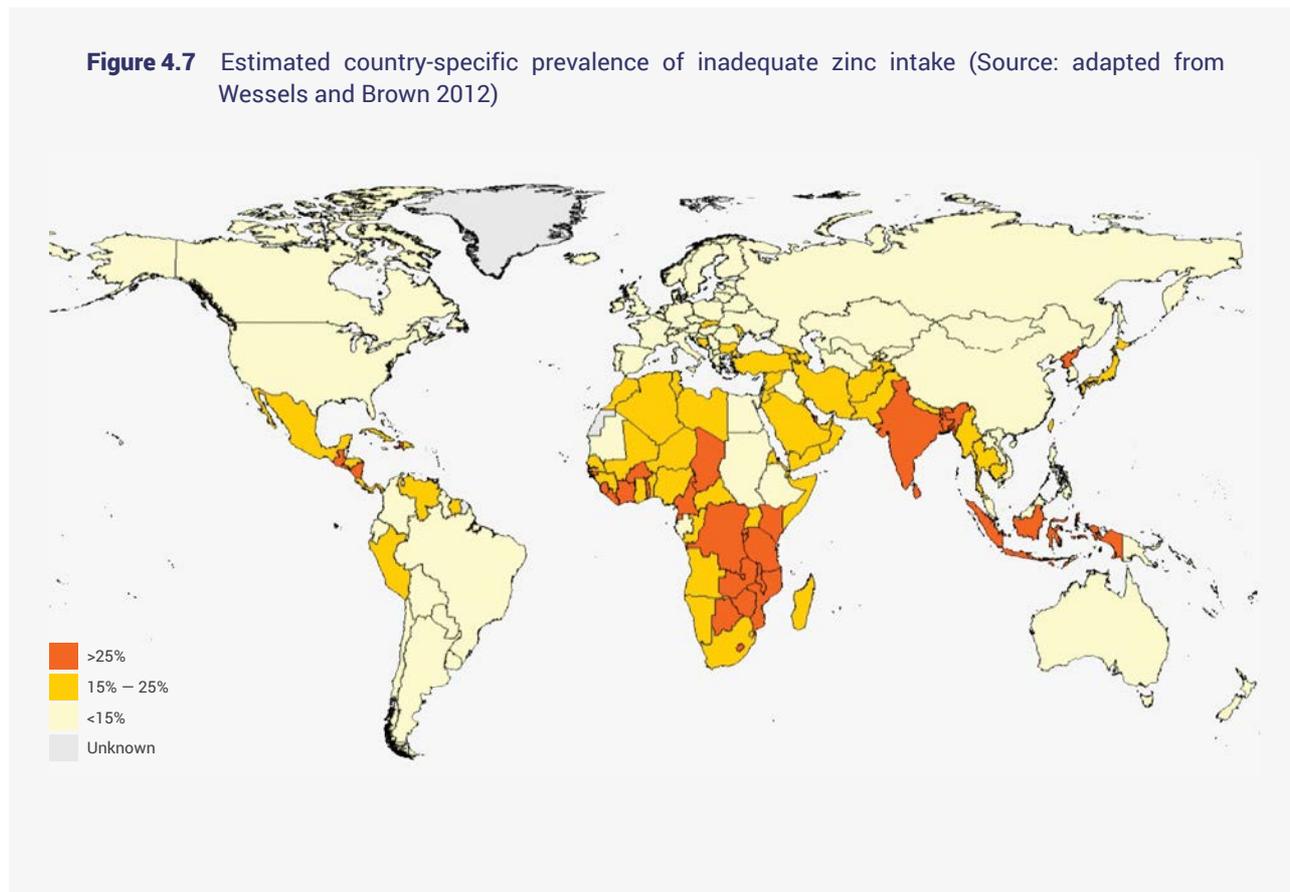


Earlier in this chapter, there is a good deal of discussion concerning the nutrition transition including high levels of animal product consumption. While this is a tremendous environmental (including climatic) and landscape burden, it should be noted that animal products are a great source of several micronutrients that show high rates of insufficient intake globally (e.g. iron, zinc, and vitamin B₁₂). However, far lower meat intakes than the U.S. pattern or even than the current global average are sufficient for a population to meet recommended levels. If, for example, everyone ate about the average of 42 kg/yr or 115 gm/day, then, on average, about 35-50 per cent of the protein requirement and a significant per cent of key micronutrient requirements would be met by meat (see McMichael *et al.* (2007)). Three things should be noted here: this is true in the context of a healthy diet – not instead of one. Also, this assumes the meat-ingesting population has a low or zero burden of parasites, such as hookworm and schistosomiasis. Ensuring human health in the context of food means an ample, diverse supply of fruits and vegetables, as well as whole grains and plant legumes. In combination, this provides a strikingly rich micronutrient intake.

Undernutrition at its extreme manifests as famine, an episodic event has the potential to become even more frequent and devastating due to enhanced environmental

change compounded by conflict (or conflict compounded by environmental change). For example, in March 2017 the UN emergency relief coordinator warned of the worst famine since 1945 with 20 million lives at immediate risk in South Sudan – with climate change as the primary trigger compounded by war (Falk 2017). It is likely that famine will be more common moving forward as climate change and fresh water shortages both directly impact the food supply and potentially lead to more conflict.

Figure 4.7 Estimated country-specific prevalence of inadequate zinc intake (Source: adapted from Wessels and Brown 2012)



4.9 FOOD LOSS AND WASTAGE

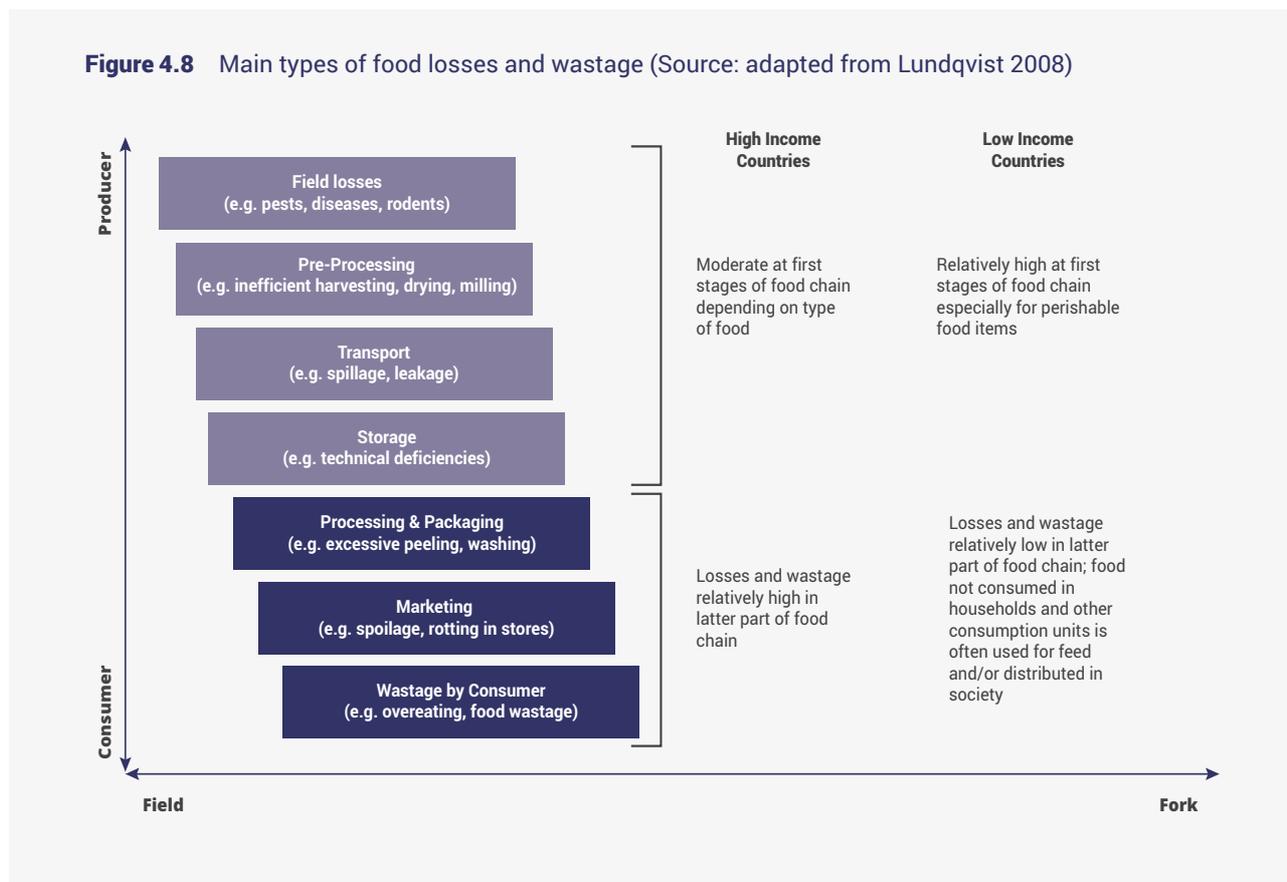
Though it might sound trite, people cannot be healthy if they do not have food. Harvest and post-harvest management of crops and animal products is critical to ensuring food gets to people's mouths in as pristine a state as possible – without contamination (chemical or biological) and with minimal decline in nutritional quality. The loss of foodstuffs across the food supply chain is one of the more vexing problems for a variety of reasons. Food that is produced and never finds a human stomach – or an animal intermediary – has typically used land, water, fertilizer (and/or compost), mechanical farm implements (often), and human labour in its production, yet it never satisfies anyone's hunger, needs, or wants. Food that is produced and never consumed also means that more land and resources will need to be used to fuel a growing global population, since what is currently produced is inefficiently captured in and along the supply chain.

While estimates vary, it is generally considered that somewhere between 30-50 per cent of all food that is produced is wasted (Fox and Fimeche 2013), with FAO (2011) estimating about 1.3 billion pounds of food wasted per year. How much of what is lost varies greatly

across regions. As illustrated in **Figure 4.8**, these losses occur at a number of stages. Developed countries have relatively few losses in the early stage of the food system supply chain, but a great deal of wastage by consumers. Conversely, developing countries have high losses in the early stages and relatively low losses later.

However, this is not absolute. The developed world has much to improve in terms of strategies around consumer perception and perceived marketability. For example, a study of the Swiss potato supply chain indicates there is about a 53 per cent loss along the chain, with 40 per cent of that loss due to consumer preference (Willersinn *et al.* 2017). In the U.S., it has been estimated that approximately \$166 billion dollars of fresh food is lost each year, most of it as consumer wastage – 41 per cent of meat, fish, and poultry, 17 per cent of vegetables, and 14 per cent of dairy – about 124 kgs per capita (2008 data) (Buzby and Hyman 2012). There is a large greenhouse gas (Heller and Keoleian 2015) and water footprint cost to this loss and waste.

Figure 4.8 Main types of food losses and wastage (Source: adapted from Lundqvist 2008)



Beyond consumer wastage in the home, there is much that can be done. Enhancing urban food security for a burgeoning urban population necessitates doing more – food-preserving harvest and food chains will be even more important going forward than they are now, with lower rural and higher urban populations. In a TEEBAgriFood Framework, identifying food system typologies that afford the best blend of health and environmental sustainability implies insuring significant reductions in food waste.

In the developed world, much of this food loss could be used to reduce imports and preserve land in other countries for domestic consumption – with implications for biodiversity conservation as well (Lenzen *et al.* 2012). So what would it take to reduce food losses and wastage in the developing world? A large percentage of losses occur at the farm – either through field losses and/or incomplete harvest due to poor equipment, lack of labour, and/or lack of perceived/actual markets. Crop losses also occur due to inappropriate storage, where better technology could decrease post-harvest losses early in the supply chain.

4.10 SUPPLY CHAINS, ACCESS, AND AVAILABILITY: THE TEEBAGRIFOOD FRAMEWORK AND FOOD SECURITY

Farmers need robust markets, and population growth and urbanization affect market trends. Supermarkets have increased in number dramatically worldwide (Reardon *et al.* 2003; Weatherspoon and Reardon 2003; Traill 2006), raising a number of questions about their role in improving health status and food security. Do supermarkets provide a healthier package of food options than traditional markets? Are supermarkets accessible to the most food vulnerable? Do supermarkets provide a greater range and number of livelihoods across a spectrum that feeds back on improving health and food security? Do supermarkets provide a good strategy for traditional farmers to enter the market or do they skew the production framework? These questions can have very different answers in different parts of the world, with a number of confounding factors. Each of the food system types described by Gomez and Ricketts (2013) have strengths and weaknesses relative to food security and healthy diets. **Figure 4.9** shows that,

in a sample of developing countries, traditional markets provide a large percentage of the fruit and vegetable market, but they tend to be more seasonal in nature. This will tend to have a positive impact on consumption of many micronutrients, at least while in-season.

In addition, traditional markets tend to provide more livelihood opportunities in the value chain for fresh product. Can modifications increase year-round availability? Is this useful?

Modern-to-traditional markets are able to move more processed goods into traditional markets at relatively low cost, thus providing greater options for consumers at these markets and providing a greater diversity of products for lower-income buyers. These points of sale also have the potential to move fortified foods (e.g. iodized salt; B-carotene enriched oils) into populations. However, low-nutrient foods/beverages (think carbonated soft drinks) are also more readily available, contributing to the rising rate of obesity and diabetes in the developing world. The traditional-to-modern trend is typically defined as smaller and more local producers marketing through modern outlets, like supermarkets. This has the potential of increasing market opportunities and providing more income for growers. However, such opportunities may only be available to somewhat larger, more educated, and more refined producers able to meet quality standards.

Overall, using a food system perspective looking to optimize health, food security, environmental sustainability, and social equity, the picture is very complicated. For example, in **Figure 4.10** and **Figure 4.11**, Tschirley *et al.* (2014) analyzed the potential purchasing habits of consumers in East and Southern Africa in 2010 and projected for 2040. In 2010, about 40 per cent of a household's food supply was self-generated – partially reflecting the rural nature of the majority population. By 2040, this is projected to decline to 31 per cent (reflecting continuing urbanization). Importantly in 2010 the overall market (that is food purchased outside the home as opposed to food grown for their own consumption) was about 85-95 per cent composed of the traditional market sector, and this will only decline to 60-70 per cent of the total market sector by 2040 (with a concurrent slight rise in supermarket buying). Interpolating from this, it is probably true this will be an even higher per cent for the lowest economic strata. In other words, food security will not be possible without a strengthening of the traditional market sector via public policy and infrastructure (e.g. potable water, security, and others) (White *et al.* 2016) and appropriate technology (e.g. scaled, renewable energy-driven cold storage) at a minimum.

Figure 4.9 Fresh fruit and vegetable market share of modern and traditional market retail sales (Source: adapted from Gomez and Ricketts 2013)

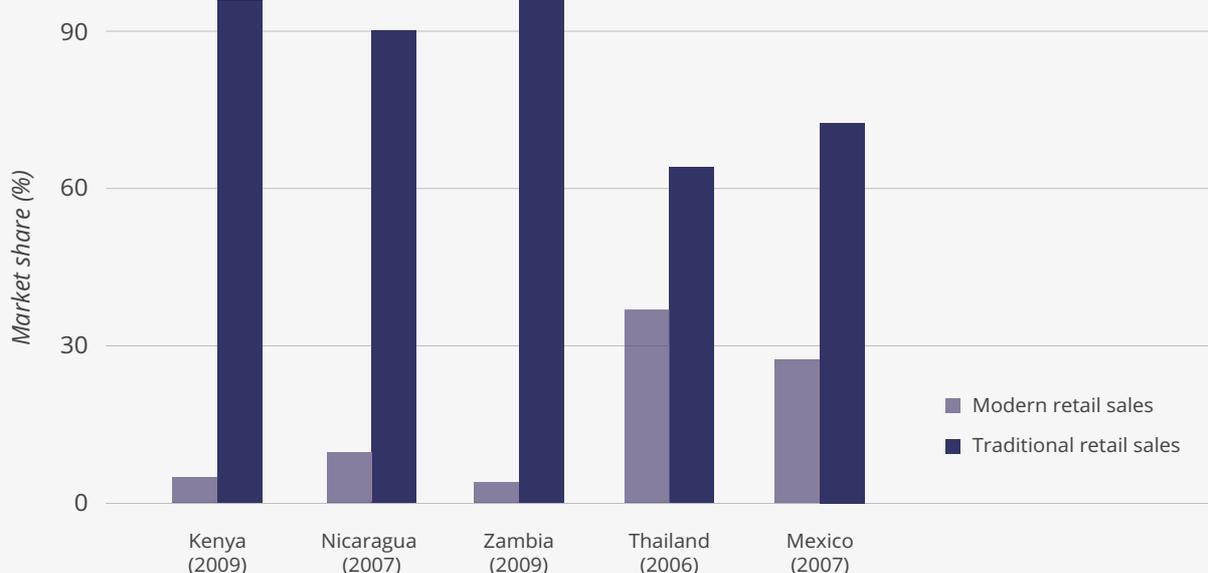


Figure 4.10 Structure of food marketing system, East and Southern Africa, 2010 (Source: adapted from Tschirley *et al.* 2014)

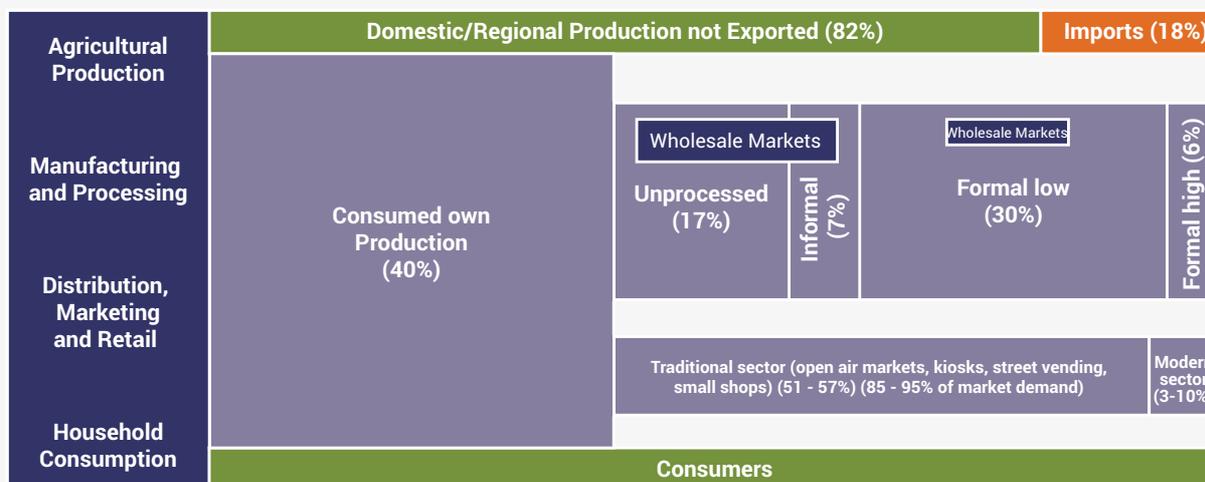
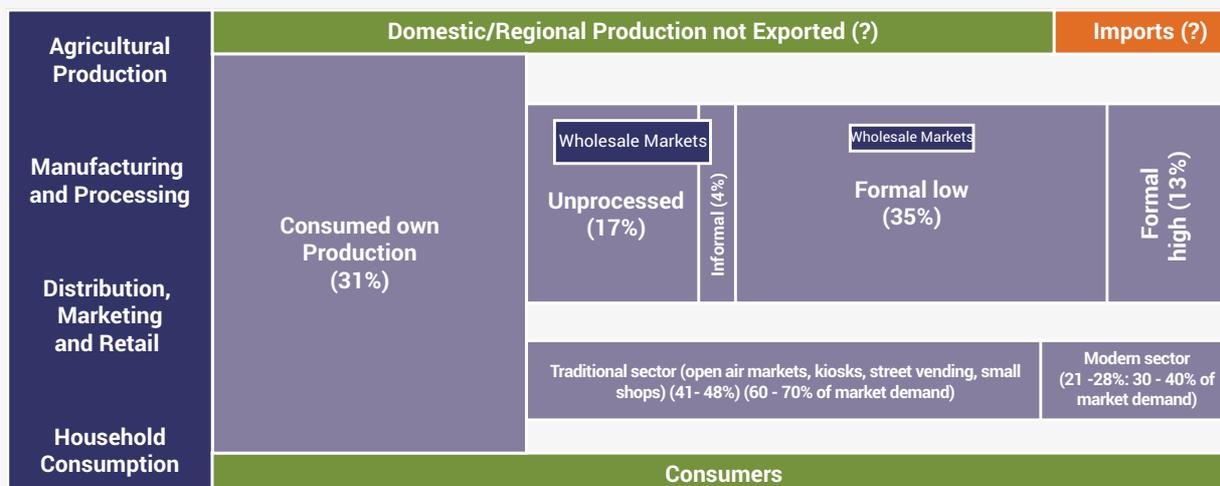


Figure 4.11 Projected structure of food marketing system, East and Southern Africa, 2040 (Source: adapted from Tschirley *et al.* 2014)



As Tschirley *et al.* (2014) identify in their modelling, the food purchasing power of the future will be very dependent on the types of economic growth trajectories implemented by governments – one that explicitly aims to spread the benefits across the economic strata will offer better purchasing power across society (i.e. greater opportunity for broad food and nutrition security). Battersby *et al.* (2016) found that those who are least food secure in South Africa tend to shop more often and for more goods in informal, traditional markets than in the emerged supermarket sector. All of these findings, while requiring further research, indicate that the supply

chain endpoint and the supply chain itself can have an impact on food security for the most vulnerable. Using the approach outlined in this report provides an opportunity to evaluate not just the economics of the endpoint of food but also to enhance food security for the most vulnerable populations, by taking stock of a wide range of sustainable livelihoods along the supply chain and illuminating the trade-offs of different types of food system supply chains.

4.11 OTHER ISSUES AFFECTING HUMAN HEALTH AND NUTRITION (CLIMATE CHANGE, LIVELIHOODS, FRESH WATER IN CONTEXT OF SDGS)

Foods differ substantially in the quantity of land, water, and energy needed per unit of energy, protein or micronutrients supplied. They also differ substantially in the amount of GHG emissions generated. Predictive studies show that, if global diets change in an income-dependent way (i.e. following the trend that people with a higher income consume more animal protein), global-average per capita dietary GHG emissions from crop and livestock production would increase 32 per cent from 2009 to 2050 (Tilman and Clark 2014). It is estimated that alternative balanced or healthier diets such as Mediterranean-type, pescetarian, and vegetarian diets could reduce emissions from food production below those of the projected 2050 income-dependent diet, with per capita reductions being 30 per cent, 45 per cent, and 55 per cent respectively *ibid.*)

Increasing global trends in meat consumption are expected to increase the GHG emissions related to food between 30-80 per cent by 2050 and can have profound long-term impacts on the availability and pricing of certain basic food commodities and access to nutritionally diverse food sources (Friel *et al.* 2009). This presents a set of complex challenges for environmental sustainability and climate change mitigation. The food system requires a shift towards much greater environmental sustainability but global food and nutrition dietary patterns continuing on their current trajectory would add to greater environmental stress in the coming decades.

Climate change affects environmental determinants of health – clean air, safe drinking water, sufficient food, and secure shelter. We cannot achieve SDG 2 (zero hunger) without addressing SDG 13 (climate action). Climate change and climate-related disasters also exacerbate many socio-economic factors and social determinants of health, such as insufficient access to education, information, and resources or ability to work; and they threaten the functioning of institutions critical for human health and well-being, including public health services and social protection systems. This undermines climate resilience and the climate adaptation capacity of vulnerable populations.

Climate change effects on water, sanitation, and energy availability have major implications for food access

and utilization (Porter *et al.* 2014) and may affect undernutrition and health outcomes (Smith *et al.* 2014). It has been conservatively estimated that, between 2030 and 2050, climate change is expected to cause approximately 250,000 additional deaths per year from malnutrition, malaria, diarrhoea, and heat stress (WHO 2014a). The global food price rise in 2010-12 may have in part been related to climate change and if so is likely to have had a significant and adverse effect on human health (Butler 2014). More negative outcomes are expected if trends continue. Compared with a future without climate change, the following additional deaths are projected for the year 2030: 38,000 due to heat exposure in elderly people, 48,000 due to diarrhoea, 60,000 due to malaria, and 95,000 due to childhood undernutrition (*ibid.*).

Populations in water-scarce regions are likely to face decreased water availability, particularly in the subtropics, with implications for the consumption of safe food and drinking water. In other areas, flooding and increased precipitation are likely to contribute to increased incidence of infectious and diarrhoeal diseases.

Most of the projected climate-related disease burden will result from increases in diarrhoeal diseases and malnutrition. Diarrhoeal diseases particularly affect nutrient absorption and food utilization. Climate change is projected to increase the burden of diarrhoeal diseases in low-income regions by approximately 2-5 per cent in 2020 and will impact low-income populations already experiencing a large burden of disease (WHO 2014a). Climate change plays an important role in the spatial and temporal distribution of vector-borne diseases such as malaria, which further affects food utilization, by increasing metabolic rate and caloric demand.

Climate change and variability can also impact the occurrence of food safety hazards at various stages of the food chain, from primary production to consumption (Tirado *et al.* 2010). Temperature increases and changes in rainfall patterns have an impact on the persistence and patterns of occurrence of bacteria, viruses, parasites, and toxigenic fungi, and the patterns of their corresponding foodborne (many diarrhoeal) diseases and nutrition (*ibid.*).

According to the IPCC (2014), if current climate change trends continue, there is 'high confidence' for increased risk of undernutrition in poor regions. According to Nelson *et al.* (2009), calorie availability in 2050 is likely to decline throughout the developing world, resulting in an additional 24 million undernourished children – 21 per cent more than in a world with no climate change, almost half of whom would be living in sub-Saharan Africa. Furthermore, Lloyd *et al.* (2011) projected that climate change will lead to a relative increase in moderate stunting of 1 per cent to 29 per cent in 2050, compared

with a future without climate change. The same study reported that climate change will have a greater impact on rates of severe stunting, which are estimated to increase in the range of 23 per cent (in central sub-Saharan Africa) to 62 per cent (in South Asia).

Springmann *et al.* (2016) also predict that climate change could cut the projected improvement in food availability by about a third by 2050 and lead to average per-person reductions in food availability. If these changes occur it could contribute to an additional 529,000 climate-related deaths worldwide by 2050. The largest number of these climate related deaths are projected to occur in Southeast Asia and the Western Pacific. Even as climate change makes food less available overall, it also has the potential to negatively impact the nutritional quality of food that is grown. A recent study highlights the potential for decreased protein content of staple crops due to increased atmospheric CO₂ (Medek *et al.* 2017; Myers *et al.* 2017) and builds on the earlier work of Loladze (2014) who also demonstrated decreases for a number of minerals including iron, zinc, and copper.

The IPCC (2014) highlighted the opportunities to achieve co-benefits from actions that reduce emissions and at the same time improve health by shifting consumption away from animal products – especially from ruminant sources – in high-meat consumption societies, toward less emission-intensive healthy diets (Smith *et al.* 2014). Sustainable and healthy diets can improve public health and nutritional outcomes while contributing to the reduction in GHG emissions and climate change mitigation goals (Friel *et al.* 2009; Tilman and Clark 2014; Green *et al.* 2015; Springmann *et al.* 2016). A general transition to more nutritious and diverse diets (with fewer processed foods and more fruits and vegetables) is likely to have a side effect of reduced GHG emissions as well as likely reductions in non-communicable diseases (Green *et al.* 2015; Milner *et al.* 2015). In other words, climate and food security are intimately connected. Dietary patterns can either play a role in mitigating the extent of climate change while insuring global food security or exacerbate the negative effectors for global food security. The TEEBAgriFood Framework can be used to determine best food system strategies for positive outcomes across all these areas.

Achieving SDG 6 (clean water and sanitation) presents a unique challenge for humanity and human health as we negotiate the 21st century. **Fresh water** is used in every facet of our society, and it is indispensable to human (and other) life. In a food system context, we use it for production, processing (including cleaning and canning), preparation, and waste handling. We have a seemingly insatiable ability to abuse water supplies across the globe and, similar to fossil fuels, we are mining ground water at our peril. We cannot substitute water for some other molecule.

Each person needs about 3-6 litres of water per day for direct water consumption to maintain health and hydration (this is for a 70 kg human). This two-fold variation depends on climate and physiological factors – 3L in more temperate environments and up to 6L in more tropical climates (Grandjean 2004). About 1.1 billion people have inadequate access to water in developing countries, and almost two-thirds of people lacking clean water access live on less than \$2/day (Watkins 2006). Many people, mostly women, spend large amounts of time collecting water each day. Beyond the direct water intake required daily, we also all need water for cooking. Combined water requirements for cooking and drinking amount to about 5.5-9L/day or 2000-3300L/year (Reed and Reed 2013). This does not include water for other domestic uses. Our most precious nutrient is far from an assured resource for most of the world's population.

Our current use of water also has implications for our future food productivity. Globally, there are about 301 million hectares of irrigated cropland – 38 per cent utilizing groundwater – with the largest acreages in India, China, and the U.S. (Siebert *et al.* 2010). If current trends continue, much of this water will be mined out over the course of this century. For example, the 451,000 km² High Plains Aquifer in the U.S. underlays ground that produces nearly 20 per cent of U.S. wheat, corn and beef on 5.7 million hectares (USDA 2013). It is estimated that 35 per cent of the Southern High Plains will be unable to support irrigation in the next 35 years (Scanlon *et al.* 2012). Recent estimates indicate that without major improvements in water usage and preservation, a large swath from Africa through Asia will be critically short of water in the not-too-distant future (World Bank 2016). This provides another compelling reason to slow population growth in the context of human rights, gender equity, education and health care.

Climate change and freshwater access will undoubtedly impact the ability of millions to billions of people to maintain or enhance **livelihoods** and hence their ability to achieve SDG 8 (decent work and economic development). Globally, vast numbers of people are engaged in food system-related jobs and livelihoods, the majority of which are within the informal economy given the overall proportion of informal jobs across 45 countries surveyed (ILO 2013). The supply chain from rural farms to markets in many countries involves a broad array of jobs – traders, wholesalers, transportation workers, small-scale food processors, caterers, and vendors. One aspect of the informal economy relative to the food system is street food, i.e. food prepared for immediate consumption. FAO estimates that about 2.5 billion people globally eat street food daily, often accounting for a significant per cent of daily food expenditures and nutritional intake (Fellows and Hilmi 2011). It is estimated that 45 per cent of all slaughtered livestock passes through the informal economy (Aliber 2009) while the informal sector buys a

significant percentage (29 per cent) of the total potatoes in the food system (Du Preez 2011). Even-Zahav and Kelly (2016) did a systematic review of the literature on the informal food economy and food security for South Africa. For many poor South Africans, the informal food sector is critical for any semblance of food security.

It is estimated that there are at least 570 million farms (Lowder *et al.* 2014) distributed across the 4.9 billion hectares of global agricultural land. The majority of these farms are under 1 hectare. They account for around 1 billion people working in the agricultural sector (FAO 2012), representing one-third of all workers. Although it is very difficult to determine with reasonable certainty the extent of the informal and traditional markets/supply chains for food across the globe, several things are clear:

- The number of people making a livelihood in the informal and traditional market sectors across the developing world is large – in the billions, when smallholder farmers are included.
- This part/type of food system has been understudied and underserved given the critical role it plays in both livelihood development and food security.
- This part/type of food system probably becomes more – and not less – critical as urbanization continues across the developing world.
- There are a number of steps that could be taken to enhance the opportunities and options for people building informal small businesses within this food system.
- The TEEBAgriFood Framework provides a good strategy for understanding differential livelihood impacts of different food system development patterns.

4.12 CONCLUSION AND MOVING FORWARD

In this chapter, we provided a broad look at the relationship between our food system both globally and locally and the promotion of human health. We described a suite of challenges across the food system – for both those whose livelihood is based in the food system and for all of us who eat. The TEEBAgriFood Framework provides an architecture for analyzing different food pathways and for identifying business strategies, government and institutional policies to strengthen food systems and community norms of behaviour. This, in turn, provides a structure for engaging across the food system in the context of today's – and tomorrow's – challenges. Finally,

it appears obvious that meeting the 17 Sustainable Development Goals and many of the associated 169 targets necessitates a large-scale effort to rethink, restructure, and rebuild our global food system.

How does the context of urbanisation, population growth, fresh water, environmental degradation, climate change, and livelihood enhancement relate to the type of food system best suited to satisfy the need for universal food security and healthy food patterns? In broad brushstrokes, on one side is an extremely globalized food system (“modernized,” in the typology used in this chapter) in which supply chains are fed by lowest cost, transportation, and cold chain (when necessary) infrastructure that are state of the art, and outlets predominantly via supermarkets of various types. In this scenario, the key is international trade on a much larger scale than currently experienced.

While an amount of global trade is both good and necessary, as it scales ever larger, it can also have a variety of negative consequences. For example, it is clear that NAFTA has helped drive an obesity epidemic in Mexico (Clark *et al.* 2012). Research has shown international trade can drive threats to biodiversity in developing nations (Lenzen *et al.* 2012). Also, there are attendant risks to supply chain disruptions and consequential impacts to local food security. High input, industrial type production systems that typically supply globalized food systems are, for the most part, environmentally unsustainable and substantially contribute to the negative health impacts described in this chapter (IPES-Food 2016). Maximizing production through expanded acreage also can drive unsustainable outcomes such as soil loss – for example, large amounts of U.S. soybeans (in 2014-15 about 45 per cent)(Newton and Kuethe 2015) and corn/corn products from the Mississippi Basin are exported annually (USDA 2014). Relatively small changes in production (i.e. taking most sensitive lands out of production and restoring perennial prairies), could have outsized impacts on nutrient and soil retention (Liebman *et al.* 2013). Transportation systems are being challenged with choke points, infrastructure weaknesses, and potential environmental impacts yielding a great deal of disruption potential (Bailey and Wellesley 2017).

On the other hand is the notion of more regional/local food systems (“traditional” in the typology used herein). These will not *a priori* ensure fair labour practices, environmental sustainability, or food security and human health (Bellows and Hamm 2001), but they do have the advantage of bringing the benefits and impacts in closer proximity to one another – and in closer proximity to the end users. While this can hopefully enable greater transparency it does not guarantee that consumers are cognizant of production and labour practices. For example, while consumers perceive that food safety, production practices, and food quality are enhanced at U.S. farmers markets (Wolf *et al.* 2005; Yu *et al.* 2017), the

reality is that the production practices of these farmers is pretty consistent with the general population of farmers (Low *et al.* 2015).

Hamm (2008a; 2008b; 2009) argues that a blend of regional (“traditional”) and global (“modern”) is what is needed – with regional being maximized to the extent that is regionally feasible across the globe. In much of the developing world, we are seeing the challenges of maintaining and improving these traditional food systems in the face of modernization, while many in the developed world are trying to rebuild these food systems within a “modern” system that has destroyed much of what had been “local”.

Throughout this chapter, illustrations of challenges and opportunities in the food system as it exists have been highlighted with respect to health. Nutrition-sensitive, sustainable food systems are fundamental to reducing undernutrition and improving nutrition security in a changing climate (Tirado *et al.* 2013). A sustainable food system would deliver food and nutrition security for all in such a way that the economic, social, and environmental basis to generate food and nutrition security for future generations are not compromised (HLPE 2014). It would nourish the world using the fewest resources possible, while improving the availability, access, and utilization of food resources over time. A sustainable food system should not only minimize negative impacts to our planet but should also integrate agricultural development, climate action, and biodiversity conservation in order to contribute to agro-ecological resilience and to positive human nutrition and health outcomes (IPES-Food 2016). Tirado and Lengnick (forthcoming) identify six key principles of nutrition-sensitive and health-promoting sustainable food systems:

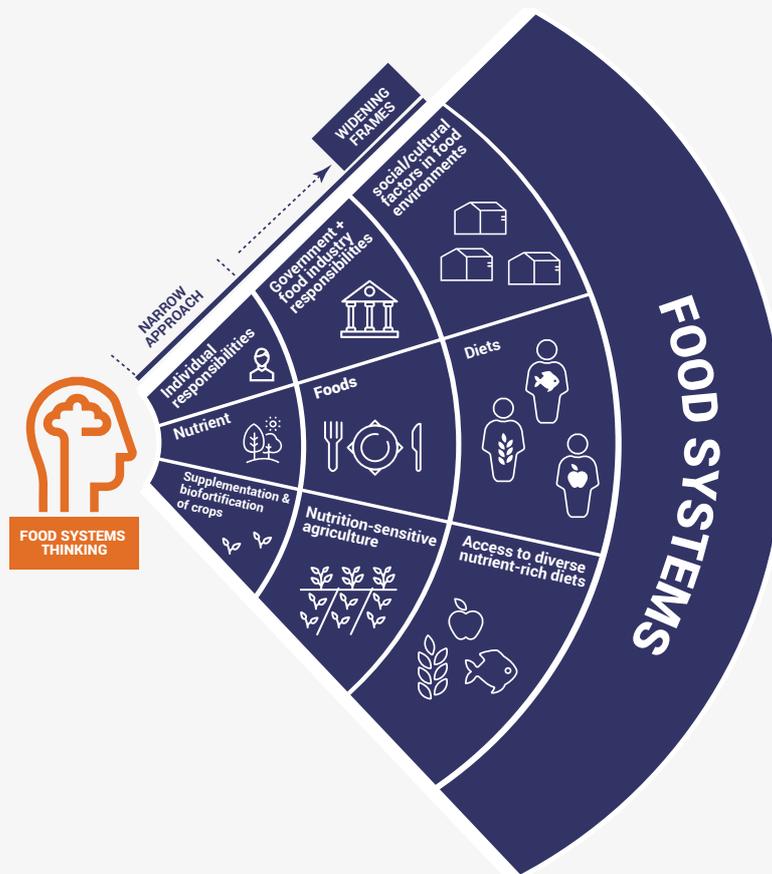
- Promote production of diverse and nutrient-rich foods: There is a need to enhance the quantity, nutritional quality, and diversity of agricultural food production for local consumption of diverse diets.
- Respect the socio-cultural context: Strategies must be suitable for the microclimate, the local and community needs, and the socio-cultural context.
- Promote healthy dietary patterns and food safety: These can lead to both a reduction in GHG emissions and improved public health and nutritional outcomes.
- Target the most vulnerable groups and ensure social inclusion and resilience: Social protection is critical through increasing households’ income, strengthening rural and urban services, and investing in sustainable agriculture so households become less exposed, less sensitive, more adaptive, and more resilient to a range of shocks.

- Ensure gender sensitivity: Women serve as agents of social change and development through their unique roles in their family and child care, livelihood generation, household food provisioning, and health and natural resource stewardship.
- Adopt a multi-sectoral approach and good governance: A number of policy, institutional, and governance solutions are necessary for the establishment of nutrition-sensitive and health-promoting sustainable food systems requiring a multi-sectoral approach.

We propose at least two additional principles should be added to this. First, there is a need to enhance demand for a diverse array of nutrient rich foods. Second, one must ensure that the food system avoids or minimizes the risks of exposure to harmful chemicals, pathogens and hazardous working conditions. The challenge, of course, is putting these principles into practice. Chapter 8 encompasses several case studies that illustrate trade-offs and strategies while Chapter 9 illustrates ways in which these principles can be implemented. As seen above, creating an environment conducive to optimal human health is extremely challenging. Human health that allows individuals to reach their potential is partially a function of individual behaviour, which is always within the context of the food system and the general environment in which they live. A person living on less than \$2 per day probably cannot be expected to eat five servings of fruits and vegetables (with the right distribution to get sufficient levels of micronutrients), whole grains for sufficient fibre, and the proper level of protein without help. Similarly, a person cannot be expected to eat properly if they do not have relatively simple access to markets that have all of these in abundance.

Personal choices are made within a context of what the built and natural environment provides; they are made in the context of their cultural heritage; they are made in the context of finances and competing needs; they are made in the context of advertising and market placement – typically skewed to high-calorie, low nutrient foods; and they are made in the context of their world view. That is why the type and structure of a community’s food system, the government and private sector policies that guide action and infrastructure development, the education (formal and informal) that is supported and encouraged in communities, and the community norms that evolve over time are critical to all of a community member’s health and well being. In the public health world this is known as the social ecological context for human behaviour. The approaches we take – a food system approach rather than a narrow problem solving approach; a systemic approach rather than a single function approach will be important to multifaceted change. As illustrated in **Figure 4.12** the breadth of our lens matters to the types of improvements and our ability to reduce the level of unintended consequences.

Figure 4.12 A food systems thinking lens (Source: adapted from IPES-Food 2017)



Trends are illustrative of how we are doing and where we are headed. In general, as outlined above, the average dietary pattern of the developed world is neither conducive to optimal health nor to environmental sustainability. There is movement among a subsector to reduce meat consumption (witness the increased level of vegan and vegetarianism) with the proposal of the Chinese government to reduce it by 50 per cent among its population (Milman and Leavenworth 2016), and yet as of now, rates of consumption are still quite high. At the same time, at least a billion people would benefit from more animal protein in their diet, although this number could be reduced by treatment for parasites. The same can be said in the opposite direction for fruit, vegetable, and whole grain consumption. There is also a trend for increased developed world food dollars being spent on food produced under a number of certifications, such as organic (with a global market increase from US\$15.2 billion in 1999 to US\$80 billion in 2014 [IFOAM 2016]), biodynamic, and fair trade. These are impacting the landscape and some of how labour is treated across the globe, although this is clearly not enough. New research indicates the potential to feed the world (with nitrogen limitation problematic) through organic production

and a concomitant reduction in food waste and animal production (Muller *et al.* 2017).

In the developing world, the challenge is one of the nutrition transition standing side-by-side with hunger – the double burden of obesity/overweight and undernutrition (WHO 2016a). Obesity is prevalent across a range of nations (Ng 2014), many of which also have high rates of undernutrition. The broad challenge here is to meet in the middle – increase the diversity and regularity of a healthy food supply across the economic strata while not increasing meat and empty calorie consumption dramatically.

It is clear from the range of studies cited here, as well as others, that a healthy and more environmentally sustainable diet would be one much lower in meat than the current U.S. (or EU average) intake with a much more plant-centred approach to protein, much higher in fruits and vegetables, higher in whole grains, and much lower in highly and ultra processed foods. It is also clear that severely reducing the use of the range of pesticides currently employed in modern production would lead to health improvements. Reducing and targeting nitrogen

and phosphorus fertilizer use in places where it is overused would also be very helpful environmentally, and in some cases also improve human health.

A variety of policies, from global trade agreements to local municipality sugar taxes to production practice mandates, are being used and/or recommended as strategies for improvement (e.g. Colchero *et al.* 2016). Hawkes' (2017) notion of policy coherence in the context of the SDG aspirational narrative at the beginning of this chapter is a useful touchstone. Do policies have a positive impact relative to the targeted SDG and, at a minimum, do no harm to the improvement of others? A WHO (2016c) report outlines a number of recommendations for greatly reducing childhood obesity - the sum total of which argues for much greater coherence between trade, agricultural, and health policy.

The NAFTA example is also illustrative of negative human health and livelihood impacts of unfettered global trade. Others argue without appropriate trade it would be difficult for many countries to provide adequate nutrition to their current populations (not to mention future populations) (Wood *et al.* 2018). This is a testable notion in communities and regions across the globe. It has also been argued that a more nuanced notion of agricultural trade is needed. As of now, the dominant priority in trade is – efficiency (defined very narrowly) –while social goals of food rights, livelihood and environmental protections are ignored (Clapp 2014). We would argue that these social goals must be prioritized if an integrated approach to the SDGs is to succeed – something that global trade agreements currently do not recognize. There are examples across the globe illustrating production diversity and market access implications to smallholder farmer health and well-being (HLPE 2017) - policies that encourage such diversity positively impact peoples' lives.

The Global Panel on Agriculture for Food Systems and Nutrition (2016) report has a similar message, namely that policy should be explicitly pointing to healthy diets. We would add that these should simultaneously incorporate environmental sustainability and human livelihood dimensions. A policy of farm diversification for improved nutrition should support agroecological methods of production as well as provide upstream infrastructure for market access and crop post-harvest management.

What is also fairly clear is the value of more regionalized food systems – food systems with a dynamic blend of regional and global, traditional and modern with a slant towards regional/traditional to the extent feasible in a particular region. This is also an area ripe for research and action. In the developed world, this has taken the form of creating short supply chains, direct sales to consumers, the emergence of food hubs, and the growth of smaller-scale agriculture among other developments. This approach has great potential, but needs to be

implemented more broadly. In the developing world the most logical first steps may well be preserving and enhancing the regional food systems that already exist – supplementing them with global supply chains of healthy food – but fundamentally building upon existing informal and formal markets. Enabling people and communities to take this approach in a manner that fosters universal food and nutrition security while enhancing environmental integrity and livelihood security is imperative and achievable. TEEBAgriFood provides a Framework for determining strategies with the potential to markedly improve the situation of this wicked problem and insure the global population as a whole have the opportunity to live healthy lives, free from the twin scourges of obesity/overweight and undernutrition. A detailed description of the TEEBAgriFood Evaluation Framework (Chapter 6), the methodology (Chapter 7), case studies applying the Framework (Chapter 8), and the TEEBAgriFood theory of change (Chapter 9) can be found in other parts of this report. Coupling this to both the SDGs and the UN Decade for Action on Nutrition provides a powerful way to move forward and ensure global food and nutrition security.

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