

Review

Hunger and Obesity as Symptoms of Non-Sustainable Food Systems and Malnutrition

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Abstract: Among the great challenges the world faces are how to ensure food security for its growing population—projected to rise to around 10 billion by 2050—so it can meet their nutritional needs for a healthy life. Current regulations and literature on food security mainly focus on food quantity (i.e., portion sizes), daily calorie intake and methods for increasing food production and too little on food and diet quality and the holistic effects of (mal)nutrition. From a systems perspective, in order to promote innovation policies for more sustainable food systems, food security cannot be viewed independently; rather, it is characterized by the interplay of an extensive network of economic, environmental and social dimensions that should all be taken into account in a comprehensive resilient and sustainable global food system. Here, we highlight one aspect of this vast network that we consider a particular challenge—yet also a great opportunity—for innovative policies geared toward more sustainable food systems: the interplay of hunger and obesity, including resulting policy strategies beyond potential efficiency improvements in farming practices. Future studies need to emphasize the importance of an in-depth understanding of the interdependencies within the global food system and its interrelatedness with societal and natural systems as part of coupled human-environment systems and in the face of continuing population growth and food demand globally. Recommended strategies for achieving sustainable food security systems include innovative educational approaches and stakeholder-driven innovation policies based on mutual learning processes between society, science, industry and policymakers, as well as fostering increased responsibility of all members of society along the agriculture and food value chain.

Keywords: sustainable and resilient food system; food security; hunger and obesity; food supply; urban and rural divergence; health; malnutrition; comprehensive system interventions; innovation; SDGs

1. Sustainable Food Systems

Malnutrition has been linked to both under- as well as overweight [1–4] and is considered the single most important threat to global public health [5–7], with data from the World Health Organization (WHO) suggesting that malnutrition accounts for the largest proportion of child mortality worldwide [8–10]. Undoubtedly, a population's nutrition, health status and wellbeing are closely linked with each other and together they can have far-reaching social, ecological and economic

impact. According to the Food and Agricultural Organization of the UN (FAO), China represents a recent example, where the country's economic development since 1978 was based on market reforms, paralleled by major improvements in the national *nutrition and health status* [11,12]. Adequate diet not only affects peoples' health, but—on a larger scale—shapes the sustainability and resilience of entire evolving sociocultural systems as a form of coupled human-environment systems.

The American Public Health Association defines a '*sustainable food system*' as one that provides healthy food to meet current food needs while maintaining healthy ecosystems that can also provide food for generations to come with minimal negative impact to the environment. A sustainable food system also encourages local production and distribution infrastructures and makes nutritious food available, accessible and affordable to all. Further, it is humane and just, protecting farmers and other workers, consumers and communities' [13]. In the real world, striving toward a sustainable food system is therefore an '*ongoing inquiry on system limit management*' in the frame of '*intra- and intergenerational justice*' [14]. Vieira et al. [15] most recently provided a systematic review on sustainability and resilience patterns in urban food systems. Literature points out that regardless of societal focus, sustainability orientation (of food systems) calls for an underlying communication system that is based on a common language and which allows for a discourse among the relevant stakeholder groups [16–18].

Extending on these previous thoughts, we define: *Sustainable food systems* provide food security for present and future generations at the local and global level, exhibit mechanisms, which enhance resilient systems with respect to internal as well as external change patterns and disturbances and simultaneously focus on associated economic, social and ecological effects along the whole food supply chain based on circular principles, from agriculture and production to food consumption and reutilization of waste. Hence, the understanding of this complex multidimensional framework and its implications at various societal levels is crucial. With respect to the resilience of a food system it is crucial to be aware of and appropriately deal with, potential threats and vulnerabilities such as possible disintegration effects within a community's food system [16], land and biodiversity degradation [19,20], climate change—for example greenhouse gas emissions related to food production [21,22], geopolitical risk related to resource availability [23–25], population growth, the specifics of changing migration and mobility patterns [26–28], competition for land use [29] and others. The effects of some change patterns could be considered as both an opportunity and a vulnerability; for example, as they concern migration and mobility (e.g., increasing biodiversity versus invasive plants) but also digitalization (e.g., precision agriculture) [30,31]. In both cases, innovation is an interventional means and a driving force of a resilient system in dealing with these change patterns.

Food security and particularly hunger is not only a central focus of 'Zero Hunger' (SDG 2) as the second of the seventeen *Sustainable Development Goals* (SDGs) of the United Nations' 2030 *Agenda for Sustainable Development* but it is related to several other goals, targets (of a total of 169) and indicators (230 in sum), which are aimed to guide strategies and actions of the international community between 2016–2030 [32]. The SDGs are more adequate in addressing the systemic effects of hunger and obesity than their predecessors, the Millennium Development Goals (MDGs; 2000–2015), which mainly targeted hunger and poverty: they now also include not only developing but also developed economies; further, malnutrition in all its forms is addressed (e.g., based on lacking food and nutrition quality). Beyond that, developing and developed economies are not only differently affected by but might also *differently perceive the single goals and targets* (with tremendous differences even within developed as well as developing economies), due to the stakeholders' potential divergence of explicit and implicit attitudes related to economic, ecological and social facets of sustainability [33]. These *attitudes* go beyond functional differences of one country being affected by under-nutrition and hunger, whereas others facing over-nutrition and obesity: large country-wise differences are related, for example, to the efficiency in production and consumption, including the occurrence of food waste at various phases of the food supply chain.

Further, if *hunger and obesity* are considered as two sides of the same coin, they are not represented within the same goal(s). Whereas hunger is strongly but not exclusively related to SDG 2 (which aims

to ‘end hunger, achieve food security and improved nutrition and promote sustainable agriculture’), obesity is a primary health concern that has traditionally been attributed to the sedentary lifestyle typically experienced in Western societies [34]. In addition, various SDGs are interrelated with the hunger and obesity nexus, most notably the improvement of health and wellbeing (SDG 3); the reduction of inequalities (SDG 10); the attempt to make cities more sustainable, inclusive and resilient (SDG 11); the strive for sustainable consumption and production (SDG 12) which, with respect to waste patterns, aims to “halve per capita global food waste at the retail and consumer level and reduce food losses along production and supply chains by 2030”; the combat of climate change and its impacts (SDG 13); related to biodiversity, the “protection, restoration and promotion of sustainable use of terrestrial ecosystems, sustainable management of forests, combat of desertification and halt and reversal and of land degradation and halt of biodiversity loss” (SDG 15); as well as one of the most effective intervention mechanisms, that is, high-quality, inclusive and equitable education and the promotion of lifelong learning (SDG 13).

We, as others [35–37], argue that an improved systemic understanding of the interdependence of nutrition, health and wellbeing is needed as a foundation for a sustainable and resilient food system.

The paper begins with the clarification of some concepts and underlying definitions of the interrelationship of food and health systems, followed by a brief outline of the interdependency between economic wellbeing and food supply at a global level since 1970 and an overview of how food security (and hunger as well as obesity) is embedded in the UN’s 2030 Agenda for Sustainable Development. Then we examine hunger as a global phenomenon, followed by a sketch of the obesity epidemic in the Western world and a discussion of a hunger-obesity paradox, because of increasing hunger within obese societies. The health effects of malnutrition related to over- and undersupply in caloric intake, food and diet quality and behavioural patterns are discussed in the subsequent sections. Finally, we examine some global food supply specifics from 1961 onwards and relate these developments to changes in urban versus rural populations as well as increasing food demands. We conclude our reflections on systemic characteristics of the food system by outlining potential strategies and policies in support of a sustainable food system (including education and training) as well as the responsibilities of different social actors as suggestions for future, extended research.

Several commonly used definitions in the context of our paper require clarification. *Food security*, “... exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” [38]. This implies that food security depends on food availability, access and quality, appropriate utilization (including knowledge/education on how to properly use) of food and stability of access to adequate food, as stated in the Rome Declaration of the Food and Agricultural Organization (FAO) of the United Nations [12]. The Rome Declaration also points out the importance of the *relationship between the quality of food and health*; yet, the intricacies of the interrelatedness of undernourishment and overweight/obesity as well as their interplay with food and diet quality, waste prevention and food waste utilization strategies, would require a more in-depth examination. It is well established that obesity represents one of the single most important lifestyle risk factors, accounting for up to 2.8 million deaths worldwide, largely attributable to an increased non-communicable-disease burden including (but not exclusively) diabetes mellitus, hypertension, cardiovascular disease, cancer and stroke [39]. More recently, obesity, which induces low-level systemic inflammation with far-reaching health consequences, has been described as anthropogenic, signalling broader environmental problems [40], including for example limited access to healthy nutrition (e.g., fruits and vegetables) or social factors such as poverty.

The right to food—another technical term—is universal (i.e., a human right) and, as such, has been put down in writing in UN charters [41]. Subsequently, the related concept of food entitlement was identified by 1998 Nobel Laureate Amartya Sen. The following definitions are mostly based on FAO, International Fund for Agricultural Development (IFAD) and World Food Programme (WFP) [5] and are outlined in Figure 1: *Malnutrition* includes under-nutrition and over-nutrition

as well as micronutrient deficiencies and is understood as an abnormal physiological condition caused by inadequate, unbalanced or excessive consumption of macronutrients and/or micronutrients independent of body weight (Figure 1). In other words, malnutrition can occur independent of body weight, that is, in both under-, normal, as well as overweight individuals. *Under-nutrition* as the outcome of *under-nourishment* (i.e., a state, lasting for at least one year) or inability to acquire enough food, defined as a level of food intake insufficient to meet dietary energy requirements—currently close to 1 billion people are chronically undernourished [42]) is characterized by deficiencies of essential vitamins and minerals (collectively referred to as micronutrients) and includes being underweight for one's age, too short for one's age (stunted), dangerously thin for one's height (wasted) and deficient in vitamins and minerals (micronutrient malnutrition). *Over-nutrition* is a result of excessive food intake relative to dietary nutrient requirements. *Hunger* has been described as a form of discomfort from not eating and as such can affect both undernourished and overweight individuals; however, in this paper hunger is used synonymously with chronic undernourishment (as discomfort from not eating, also obese people can experience hunger). Hunger is a consequence of severe food insecurity, which, in its worst consequence, can lead to starvation (Figure 1). *Obesity*, finally, refers to the over-consumption of specific nutrients, which, as another form of malnutrition, by definition is characterized by a body-mass index (in kg/m²) of 30 or greater (whereas overweight refers to a BMI of 25–29.9).

Of the global population, 11% has been undernourished in 2016, which equals a total of 815 million people [5,43]. Specifically, countries with a high proportion of under-nourished in their population tend to be those with the lowest GDP. While these numbers have been declining at the beginning of the century (from a peak in 2003 of 14.9% undernourished, totalling 947.2 million people globally, down to as low as 10.6% or 777 million people in 2015), they have recently begun rising again [43].

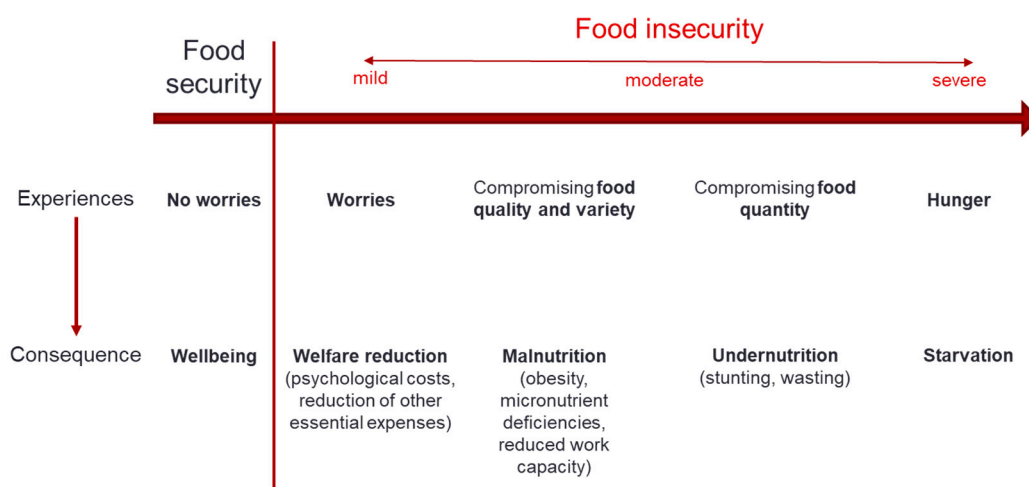


Figure 1. From Food Security to Food Insecurity (adapted from Cafiero/FAO, 2013) [5].

While various concepts and definitions of ‘wellbeing’ exist [44], which largely centre around a state of happiness, being comfortable or experiencing security/safety, welfare and health, in this paper, we will focus on traditional economic welfare expressed as GDP per capita in relation to food supply as kcal per capita per day since 1970, acknowledging that it has been widely criticized for numerous reasons including inequality (e.g., [45]).

2. The Global Phenomenon of Hunger and Malnutrition

Among adults, 1–2% of all deaths worldwide are attributable to nutritional deficiencies including malnutrition and in children ages 1–4, over 7% annually die due to hunger, resulting in 140,000 deaths of two million deaths total attributable to hunger [46–48].

Besides being a risk factor for infant mortality, the numerous negative health consequences of hunger, which often are related to societal inequalities and poor socioeconomic status, span from low

birth weight to underweight and stunting, poorer overall health, higher rates of chronic illnesses and asthma, decreased or delayed cognitive ability to higher rates of mental illness, as well as increased rates of obesity. Though the latter may seem puzzling, it ties in with the fact that parental poverty is a risk factor for obesity, independent of the socioeconomic status (SES) attained by the offspring. Part of the explanation for this is that food insecurity during childhood may lead to compensatory overeating. Further, the foetal origin hypothesis poses that prenatal under-nutrition induces permanent changes in regulatory mechanisms of energy intake and expenditure and that in-utero exposure to under-nutrition is a developmentally sensitive time period. Even though the number of undernourished individuals has declined over time, the decrease has been slow and has not equally affected all parts of the world, with the slowest progress having been made in Africa and Oceania [5].

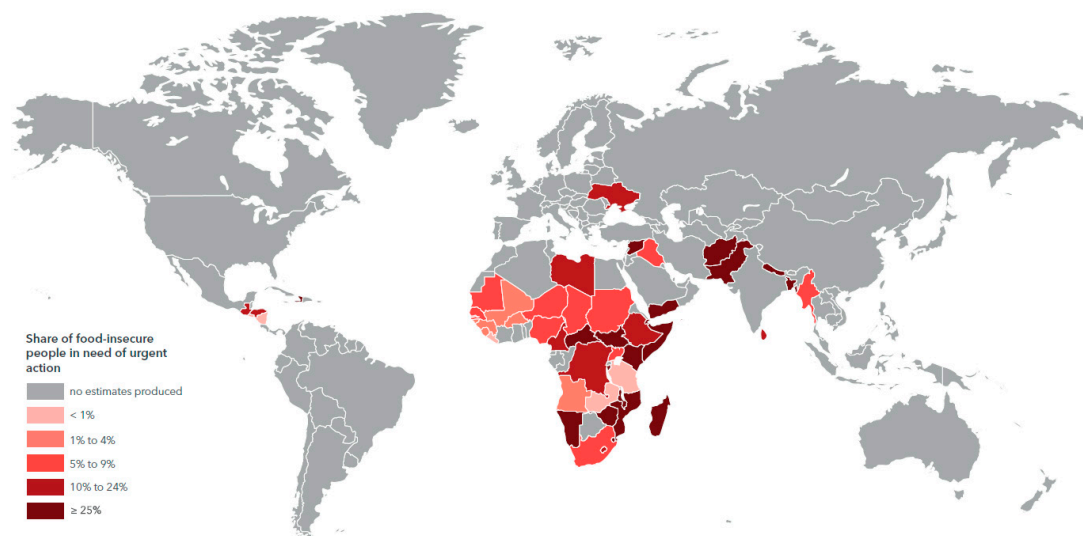


Figure 2. Share of people in Integrated Food Security Phase Classification (IPC)-Cadre Harmonisé (CH) Phase 3 (Crises), Phase 4 (Emergency) and Phase 5 (Famine/Catastrophe) in 2017. Source: Food Security Information Network FSIN [49], Integrated Food Security Phase Classification IPC [50].

Interestingly, *inequality* seems to be one particular sociocultural characteristic that correlates with both hunger and obesity. This is particularly true for socioeconomic background and education, as well as sex. In the majority of OECD countries, women are more obese than men and less-educated women show a two to three times higher probability of being overweight than women with a higher level of education [51]. On the other hand, *conflict* tends to have the most severe consequences for the poor by not only inducing greater divergence between the poor and the rich but also by aggravating pre-existing inequality. As such, conflicts become key drivers of *extreme food crises* and re-emerging *famines* [43] and cuts in food support can lead to migration movements [52]. Examples include areas of South Sudan, where famine was declared in early 2017 and northeast Nigeria, Somalia and Yemen, which are at high alerts of high risk of famine (Figure 2). All these countries experience a strong prevalence of conflict, civil war, violence and societal divergence. In 2017, nearly 124 million people across 51 countries were confronted with acute food insecurity at crisis level or worse [49]. From various major drivers, in 2017, *conflict* alone accounted for almost 74 million food-insecure people in need of urgent assistance in 18 countries and territories, and, *extreme climate events* were responsible for over 39 million food-insecure people in need of urgent assistance in 23 countries (with two-thirds of these countries in Africa) [49].

3. The Obesity Epidemic and the Hunger-Obesity Paradox

According to the most recent data from 2017, more than one in two adults and nearly one in six children are overweight or obese in OECD countries [51]. The Western world currently experiences

an unprecedented obesity epidemic, which, in the US, started in the 70ies around the time of the “energy balance flipping point” [53], which essentially refers to an increase in food supply (probably due to increasing food access). Since then,—and paralleled by a shift towards more sedentary work and lifestyles—obesity rates have grown at a remarkable rate, initially in the US and with some lag-time more recently also in Europe. For example, adult prevalence of obesity in the US is more than 36 percent and overweight rates have risen in Europe from <5% in 1984 to a staggering 50% and more today [51,54]. Observational data suggest that the chance of becoming obese increases within a relatively short time frame (i.e., 10–15 years) if a person moves into an “obesogenic” (i.e., promoting obesity, through for example, sedentary lifestyle that may involve lack of sleep, excessive intake of unhealthy food, etc.) environment, such as the US [55]. As pointed out by Robert Paarlberg,—the US is an outstanding example of a ‘too much society,’ when he refers to the US overconsumption of food and fuel and, consequently, nutrition and transportation patterns (‘as a society that eats and drives too much’); these behavioural patterns are rooted in political institutions and a national culture, which in their entirety not only affect a society’s health but also impact other dimensions such as climate change [56]. Obesity can affect a variety of facets in life, for example, a 2010 study showed that in the US up to 27% of all recruits are now too fat for military service [56,57].

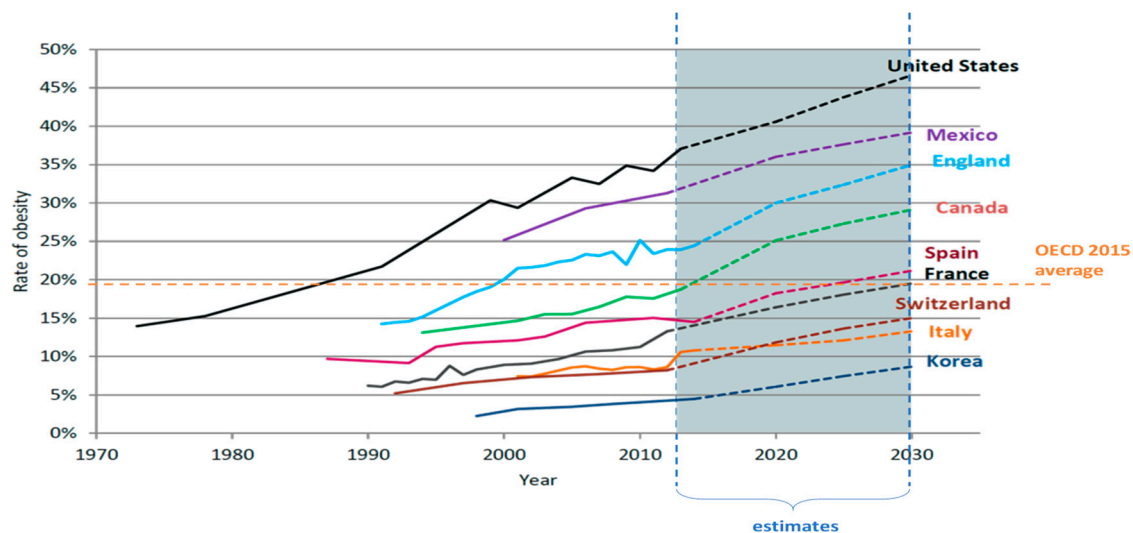


Figure 3. Projected rates of obesity. Source: Based on OECD national health survey data, Obesity Update 2017 [51].

According to OECD projections (Figure 3), *obesity rates will continue to climb until at least 2030* in the US, Mexico and England [51]: In the US, 47% of the population are projected to be obese in 2030, with more moderate increases projected for other countries for example, Italy (13%) and Korea (9%). Obesity is a silent killer, which can be held accountable for countless—particularly chronic—illnesses, most notably diabetes mellitus, heart disease and a variety of cancers [58]. In sum, there is reason for concern and an urgent need for action. Among the many risk factors for obesity, unhealthy nutrition is gaining increasing attention. In the US, a stepwise approach towards fighting the obesity epidemic has been implemented as early as 1999, initially targeting increased awareness, then later implementing state programs and more recently involving the food industry [59,60]. These measures are starting to show signs of success in the form of a modest decrease in childhood obesity rates, which, for the first time in decades, has recently been reported [61]. Meanwhile the European Union, after several unsuccessful information campaigns, is discussing a ban on marketing targeted at children and better nutrition labels, as newer and potentially more promising measures to fight this out of control epidemic [62].

Even though still on a modest scale, the paradoxical situation of a co-existence of both obesity and hunger is real, particularly in middle-income countries such as Mexico, India and China. One of the US

prime examples of staggering obesity rates, the district South Bronx in the city of New York (obesity rates, since years, top the nations' obesity rates) also has the highest proportion (37%) of individuals who cannot afford food. This, as well as other data, *strongly points towards diet quality as one of the prime culprits for the paradoxical co-existence of two opposite states on the food security scale*. And indeed, research suggests that the amount of weight gained is strongly related to the type of diet people consume. A recent study using large US databases [63] demonstrated that the biggest weight gain is achieved by those who consume larger amounts of potato chips, meat, sweets or butter, for example; whereas those whose diet comprises more fruits, whole grains and nuts, seem to lose weight most easily. In most countries of the world, underweight and overweight rates tend to inversely correlate with each other. However, besides the above discussed paradox in parts of the Western world, several low- to middle-income countries also show positive associations between under- and overweight and this correlation appears to exist independent of socioeconomic status (SES) [64]. Examples where *high rates of underweight co-exist with high rates of overweight/obesity* include Albania, Turkey, Morocco and Jordan, as well as Zambia, Mozambique and Burkina Faso. Taken together, this suggests that, even though the coexistence of under- and overweight may not yet have occurred at a large scale, the development of this paradoxical situation ought to be carefully monitored.

4. Development of Global Food Supply over the Past Five Decades

When examining changes in food supply (which FAOSTAT defines as food production + imports—exports—other uses) since 1961 by food sources globally, several important trends become apparent, some of which have previously been discussed (e.g., [65]): (1) food supply rose globally by roughly 1000 kcal/capita/day over the past 50 years (Panel A, Figure 4); whereas rural populations disproportionally declined relative to urban populations in every continent with the exception of America (population shown in billions per continent, by urban versus rural population; see Panel D, Figure 4); (2) increases in animal product supply took place in the 60ies and 70is in Europe and to some extent also in America [65] (Panel C, Figure 4), paralleled by their increasing economic wellbeing (measured in GDP; data not shown); (3) Asia and China in particular, has been catching up rapidly with regard to animal product supply since the 90ies (Panel C, Figure 4). Lastly, total food supply from vegetables was highest in Europe, in 1961, where it has stayed steady over the past 50 years, whereas in all other continents it was lower and has risen to the same level as in Europe over the years (Panel B, Figure 4). Further, nationally recommended diets exhibit environmental impacts (in addition to their health impacts), which only recently are begun to be taken into consideration (see for example Behrens et al.'s work towards standardized baseline to optimize recommended diets also with regards to their environmental impact [66,67]). In sum, several factors including the trend of increasing global food supply with simultaneously decreasing rural populations as well as the potential environmental impacts of nationally recommended diets call for new approaches to satisfy globally increasing food demands and keep this system in balance as it pertains to the environment and to logistics for food supply in urban areas or labour shortage in rural areas. For example, the ongoing rural-to-urban migration might partially be reversed by enhancing the *connectivity between rural and urban areas*, such as by technological means and infrastructural opportunities (e.g., transportation technologies, logistics and digitalization) but also by 'soft infrastructure' related to knowledge, culture and social support changes [15,28].

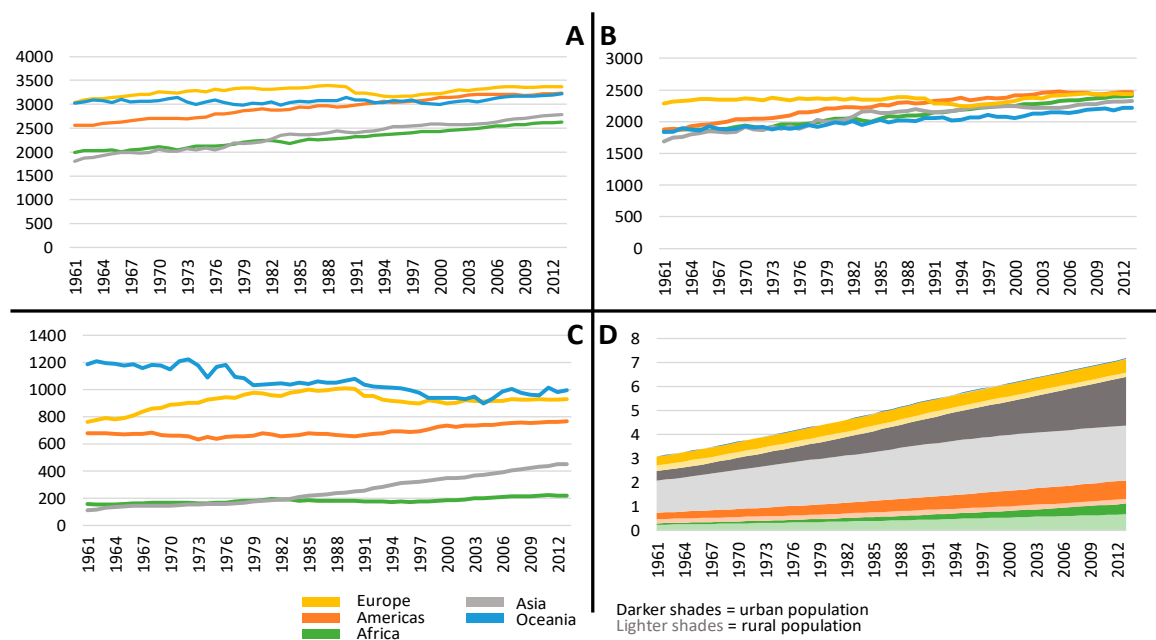


Figure 4. (A) Total Food supply since 1961 (y-axis: kcal/capita/day); (B) Food supply from vegetable products since 1961 (y-axis: kcal/capita/day); (C) Food supply from animal products since 1961 (y-axis: kcal/capita/day); (D) Urban and rural population developments since 1961 (y-axis: population in billions). Data derived from TED, FAO and IFA. All panels grouped by world regions as indicated in colour legend.

5. Food Security in the Face of Increasing Food Demands

The global rise in demand for crop production is largely driven by (1) an increase in food demand, which, in turn, is strongly related to population growth; (2) predictable shifts in dietary patterns also referred to as ‘nutrition transition’ [68,69] and related increase in fodder use due to increase in meat consumption (e.g., it has been postulated that 38 kg of grain are required for the production of 1 kg pork protein; and 61.1 kg of grain for the production of 1 kg beef protein) [70]; and (3) by an increase in biofuel production. Estimates put the increase in crop production needed by 2050 between 60% and 110%, depending on whether they consider food demand alone or in conjunction with biofuel consumption. FAO’s production estimates, for example, do not consider the increase of agricultural production for biofuels; consequently, their estimates project a 60% increase in crop production required by 2050 [71]. In regard to the land resource—food price nexus, Obersteiner et al. [29] outline its implications on the 17 SDGs and show that economic and growth pathways account for lesser impacts compared to resource-use and management policies.

When focusing on four key crops that account for approximately 75% of global agricultural calories—maize, rice, wheat and soybean—big discrepancies between projected and needed yields are anticipated to exist by 2050 [72]. With the need to substantially increase agricultural production by 2050 (e.g., FAO estimates an increase by 60% [71]), annual expected growth rates of maize (1.6%), rice (1.0%), wheat (0.9%) and soybean (1.3%) lag far behind the needed growth rate of approximately 2.4%. The currently expected growth rates translate into a global growth of 67% in maize, 42% in rice, 38% in wheat and 55% in soybean; hence, business as usual will definitely lead to rising food insecurity worldwide. Furthermore, large regional differences in crop productivity exist, globally. As an example, in Africa, rates of maize yield are increasing in, for example, the Nigerian states of Yobe and Adamawa, in Ethiopia, Angola, South Africa and Madagascar but maize yield rates are decreasing in Morocco, Chad, Somalia Kenya, Zambia, Zimbabwe, Rwanda, Burundi and the Democratic Republic of Congo [72].

The application of fertilizers is currently the only available anthropogenic measure to provide additional nutrients to the soil and to enhance its fertility, which helps to boost crop yields. Fertilization, either organic or mineral-based, has the purpose to supply soils with nitrogen, phosphorus and potash (potassium) as the three most important macronutrients for crop growth. According to the International Fertilizer Industry Association (IFA) [73], global fertilizer demand is expected to grow; it was 176 megatons in 2011–2013 and is expected to be around 179.5 megatons in 2013/14 and 184.3 megatons in 2014/15 [74]. The share of Nitrogen accounted for approximately 58 percent, phosphate for 24 percent and potash for the remaining 18 percent. Of note, inequalities for different stakeholders and regions relate to the global fertilizer value chain. For example, China, the United States and India are the top three fertilizer consumers, accounting for 58% of the world consumption in 2010 [75], whereas Sub-Saharan Africa—as one of the three key developing regions besides Latin America and South Asia—imports only small amounts of fertilizers [76]. Given their low crop productivity rates, Sub-Saharan Africa's fertilizer application rates are still far too low, averaging 10 kg of nutrients per hectare (ha) arable land (with huge differences between Sub-Saharan countries and with South Africa as the only significant African importer), in comparison to 86 kg/Ha in South Asia, 118 kg/Ha in Latin America, 198 kg/Ha in an average middle-income country and 288 kg/Ha in a high-income country [77]. On the other hand, with its own maize yields decreasing as mentioned above, Morocco is simultaneously the largest exporter of phosphate rock (PR) worldwide, with 2,575 kilotons in 2010 [76].

Another critical dimension of food security relates to food waste. A study by the Swedish Institute for Food and Biotechnology (SIK) and the FAO in 2011 confirmed that approximately 30% of edible food for human consumption will be wasted (or lost), equalling approximately 1.3 billion tons per year [78]. Although a global phenomenon, big regional differences exist with respect to food waste occurring along the food supply chain (FSC). Food losses occur at the beginning of the FSC in production post-harvest and processing stages, whereas food waste occurs during retail and final consumption [79]. This distinction is important in order to highlight regional peculiarities in consumption patterns. The study further outlines that the per capita food waste and losses of 170kg/year in Sub-Saharan Africa can mostly be attributed to losses in the early stages of the FSC, whereas only 6 kg/year can be attributed to food wasted by consumers. In comparison, per capita food wasted by consumers in Europe accounts for 95 kg/year in Europe and 95–115 kg/year in North-America, as part of a total of 280 kg/year in Europe and 300 kg/year in North America per capita food losses and waste. At a global level it shows that 222 mega tons of food waste at the consumer level in industrialized countries equal almost the total net food production of 230 mega tons of Sub-Saharan Africa. In addition, food losses and waste become a growing global problem with respect to their deposition at landfills, leading to pests, toxic liquids, odours and methane gas as a tremendous risk for climate change. While recent policies are beginning to tackle the issue of food waste (e.g., in France, a law was introduced to prohibit supermarkets from discarding food, requiring it to be donated) [80], the success of such pocket-efforts remains to be seen.

6. Strategies & Policies towards a Sustainable Food System & Responsibilities

From a systems perspective and as outlined in the previous sections, food security is not an independent, self-contained affair [28,81,82]. For example, it is compounded by the planet's increasing water and land scarcity, soil, land and biodiversity degradation and climate change leading to more frequent and severe weather events and their impact on agriculture. Any effort to strive towards a sustainable and resilient food system has to go beyond merely boosting production in order to meet the crop yield targets for an expected world population of around 10 billion people in 2050. Rather, under the umbrella of economic, social and ecological sustainability and with respect to innovative and systemic interventions to be developed, one has further to differentiate between various economic, financial, sociocultural, political, legal, institutional, technological, infrastructural/built environmental

and ecological subdimensions including their interplay as part of a multi-layered societal innovation system [83].

Various potential strategic options might be outlined when aiming at food security and health as the two core dimensions of a sustainable food system:

- (1) measures for an increase in food production, either by boosting crop yields of today's agricultural land by more sophisticated seeds (e.g., hybrid seeds), improved fertilization (and application of 4Rs [84]) and irrigation systems (e.g., the use of cheaper drip-irrigation systems for smallholder farmers [56]), in general, efficiency improvements along the entire foods values chain including better logistics and storage systems (to avoid food losses during production, storage and transport; for example, vertical farming), and/or, by clearing further land for agriculture under the consideration of the land resource–food price nexus [29] or, more generally, by adopting new land-use scenarios under consideration of given path dependencies; all of which geared towards closing yield gaps (the difference between observed versus regional attainable yield) through nutrient and water management;
- (2) food losses and waste prevention, alternative uses and recycling;
- (3) avoidance of food overconsumption and changed quality related consumption patterns, including increases in organic food production;
- (4) hybrid solutions of (1), (2), and/or (3) (as core element of comprehensive system interventions);
- (5) the development of health programs, which build on joint (pro)active and passive health-related nutrition initiatives and a higher awareness regarding own food consumption patterns as well as their consequences including behavioural change (nudging); and
- (6) the establishment of food and health policies including taxation and appropriate educational measures, which build on the increased responsibility of all members of society.

Such strategies will also depend on *technological and social innovations* at various levels of society (including stakeholder-driven innovations), awareness building among and educational measures to increase the competences of, various stakeholders of society in order to deal with vulnerabilities within the food system and to strive for resilience and sustainable development, as well as for more systemic policies, which integrate strategies related to overweight (and obesity) as well as those related to undernourishment and cost reduction as potentially helpful promoters within a sustainable food system. Consequently, not only the 'real' effects of innovation (at various levels of the food system) are relevant but also, from an ex-ante perspective, the *mental process of simulation of innovation* within food systems is crucial in understanding the potential sustainable transition path, which may ultimately lead to a resilient food system [85].

The provision of agricultural technologies for the poor tends to be considered a "support service" by rich countries for the poor. However, rather than considering this as a Samaritan act, market-based strategies ought to be taken into consideration as well. As reminisced by Stanford's former president William Miller (as part of a personal conversation in Palo Alto and example for bottom of the pyramid strategies [86]): when a technology provider on a 'Samaritan mission' went to India 'as a socialist' to provide irrigation systems to poor smallholder farmers, he returned to California as a 'capitalist'; the key to success was not to provide highly subsidized expensive irrigation systems to these farmers but to be innovative in providing the same basic functionality at reduced product costs and simultaneously opening a huge new market of relatively poor farmers, who had become the customers of a new product which had not existed at such a price before. Consequently, although profit margins were relatively small per water pump, the incredible number of new customers built the basis for a new business model based on cheap affordable technology.

If one wants to take the paradigm that focuses on maize, rice, wheat and soybean (as the cornerstone of global agricultural, constituting 75% of its calories) one step further, technology might go beyond strategies that focus on production improvement (e.g., genetically modified organism, artificial food, vertical gardening). The development of niche strategies and required system innovation

(which includes also innovative educational approaches for all stakeholders within the food system from production to consumption), for example, may, over time, lead to a *change of paradigms*. From this perspective, an approach may focus on alternative sources of protein rather than merely striving to increase existing production patterns. As an interesting example of food system innovation, AgriProtein Technologies, a South African eco-business case is based on a fly project which leads to paradigm changes along various dimensions [87]: (1) Recycling of waste nutrients (e.g., waste from supermarkets or abattoir waste from industrial slaughterhouses) by; (2) rearing fly larvae (which consist of around 55% proteins) on these waste nutrients and; (3) producing larvae meal to replace fishmeal in industrial farming. The effects of this fly project are manifold: waste is reduced, less need for other primary resources of feed (e.g., soy) and waste as secondary resource is substituting primary resources, thereby closing a nutrient loop. Although country-specific restrictions have to be considered (e.g., the use of waste streams for insect production is forbidden in the EU), other successful examples of waste nutrient recycling are, for example, known in Kolkata where fish are grown in raw human sewage [88]. Further research on the potential transmission of infectious pathogens and other health issues would be beneficial to gain broader public acceptance of projects of this kind.

7. Conclusions and Future Implications

Today, there is broad agreement among societies around the globe—as expressed within the United Nations’ Sustainable Development Goals—that food security represents a key element of resilient and sustainable food systems, which concerns developing and developed economies alike and is related to improved health and wellbeing and, ultimately, social cohesion. The overarching goal of this paper is to contribute to an enhanced systemic understanding of the interdependence of nutrition, health and wellbeing. We argued that an in-depth understanding of highly complex food systems is a prerequisite for the development of effective interventions and innovation policies at various societal levels that are striving for a sustainable and resilient food system. In contributing to a better understanding of food systems, this paper also explored the role of health status and food supply/-quality within the context of global food security, the interdependency between economic wellbeing and food supply and particularly the phenomena of hunger and obesity. The discussion was complemented by an analysis of global patterns since 1961 concerning total food supply, urban and rural population developments and food supply from animal products and vegetable products. From a systems perspective, food and health policies need to be considered as two sides of the same coin and so are economic wellbeing and food supply, hunger and obesity, food-/nutrition shortage and food waste, overproduction/-consumption and land-/biodiversity degradation, decreasing population in some parts and increasing population in other parts of the world (with a general population increase globally if no other system disturbances such as epidemics, natural disasters or wars will occur), urban and rural population developments, extreme food crises and migration movements, overweight/obesity and education, among others.

On that ongoing ‘journey of understanding,’ still a long way lies ahead of us. Future studies need to put more emphasis on an in-depth understanding of the interdependencies within the global food system and its interrelatedness with societal and natural systems as part of coupled human-environment systems and in the face of a continuing population growth and food demand globally, which as a matter of fact, cannot be satisfied with today’s technological possibilities alone. Looking ahead of us, any attempts to improve the food system’s resilience and sustainability requires innovative educational approaches and stakeholder-driven innovation policies based on mutual learning processes between society, science, industry and policymakers and an increased responsibility of all members of society along the agriculture and food value chain (including industry, farmers, traders and retailers, consumers, citizens, policymakers and other stakeholders).

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