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Towards Sustainable Food and Agriculture Systems

Summary – Over the last 50 years global food production has almost tripled. This increase has enabled the global agrifood system to satisfy the rising food demand. Notwithstanding this result, in 2017 821 million people suffered from undernourishment, because of unequal distribution of food around the planet and within countries, and inefficient food distribution and utilization. Undernourishment is accompanied by the mirroring problems of malnutrition and overnutrition. The spectacular increase in global food production has often been achieved at the cost of erosion of the natural resources that form the basis of agriculture, including land, soil fertility, water, energy and biodiversity. In addition, global food losses and waste are estimated to reach the level of roughly one third of the food produced for human consumption, or 1.3 billion tons per year. Food and agriculture system are therefore called to undertake the transition towards their sustainability. This paper critically analyzes the global food demand and the factors that are triggering its evolution, and the related environmental consequences, and discusses possible policy options for meeting the increasing and changing food demand, while taking into consideration the sustainability of the food production systems. Both increase of production efficiency and food demand restraint options identify important issues and indicate possible ways out, but do not seem to offer comprehensive responses to present and future challenges. A more integrated approach is offered by the «food system transformation» strategy, which considers production and consumption patterns at the same time, addressing also the social and economic inequalities. Such a systemic transformation can only happen through both sustained generation of new knowledge and enhanced translation of knowledge into use.

Keywords: Sustainability, food security and nutrition, food losses and waste, malnutrition, food demand.

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Introduction

Every day the global agrifood system, made of 570 million farms, delivers on average 19.5 million tons of cereals, potatoes and other roots and tubers, fruits and vegetables, 1.1 million tons of meat, and 2.1 billion litres of milk, that means 23.7 million tons of food, worth of 7 billion US dollars (Sonnino, 2015a), as well as fibers, fuels, building materials and other raw materials, not to mention a number of ecosystem services. This result has been made possible by the rapid growth of agricultural production, which over the last 50 years has almost tripled (+286%), mostly due to yield increases (Sonnino, 2015b). This production increase has enabled to satisfy the food demand of rapidly growing global population, which doubled between 1960 and 2003. Net production index, net per capita production index and population index from 1961 to 2014 are shown in Figure 1. The current theoretical food supply amount in 2013 to 2,884 Kcal/capita/day (crops primary equivalent, source: FAOSTAT), a figure that exceeds the nutritional needs of human beings (Sonnino, 2014).

Notwithstanding this result, in 2017 the number of chronically undernourished people in the world is estimated to be as big as 821 million, or one out of 9 people (FAO, IFAD, UNICEF, WFP and WHO, 2018), and, what's more, about 98% of the food-insecure people live in developing countries. Food insecurity is therefore effect of unequal food distribution around the planet and within countries and not of lack of food availability. On top of the ethical consequences of this situation, undernourishment has an estimated economic cost between 1 and 2 trillion US dollars per year, that means 2-3% of world GDP.

As the Nobel laureate Amartya Sen (1981) said, «Starvation is the characteristic of some people not having enough food to eat. It is not the characteristic of there being not enough food to eat. While the latter can be a cause of the former, it is but one of many possible causes».

According to FAO, 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» (FAO, 1996). There are four dimensions of food security: the availability of food; access to food; utilisation of food; and food system stability. For food security objectives to be realised, all four dimensions must be fulfilled simultaneously. The first dimension covers the availability of good quality and nutritious food from local, regional and international sources. It therefore includes issues of food production and processing; trade imports and exports; availability of food stocks and food aid. The second dimension covers physical and economic access to food for an active, healthy life. This includes marketing and transport infrastructure, food distribution systems and markets; purchasing power or having the money to buy the right food; social programmes to ensure access to nutritious food; and school meals which are nutritious and appealing to children. If food is available but people do not have the money to access it, they are food insecure. The third dimension covers the safe and healthy utilisation of the food. This

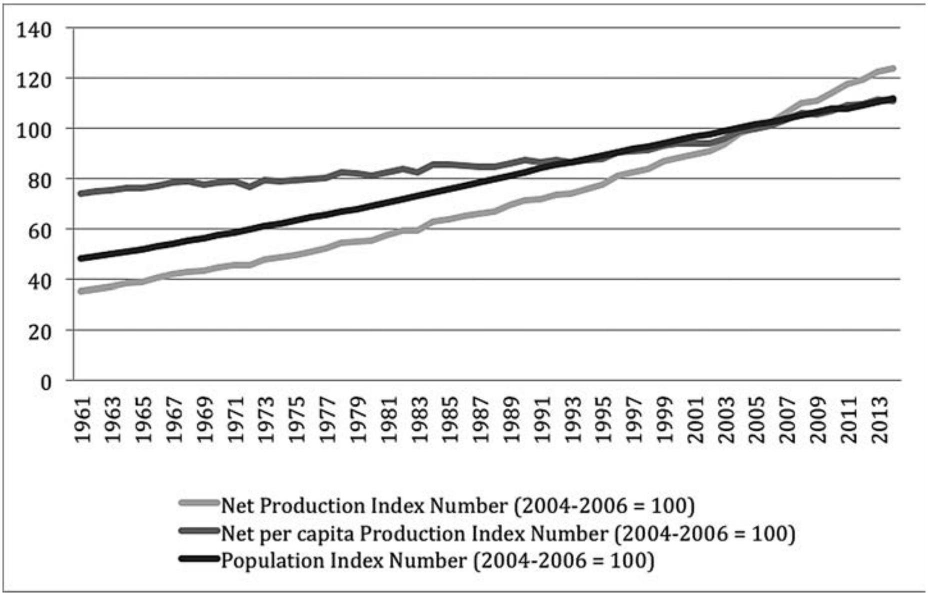

Fig. 1. Net production index, net per capita production index and population index (2004-2006 = 0) from 1961 to 2014 (source: FAOSTAT).

includes good health status, since healthy individuals can make proper use of food; having nutritious food choices for all age groups; food safety and quality; and access to clean water and sanitation. The fourth dimension covers the fact that to be food secure, a population, household or individual should have access to adequate food at all times and should not risk losing access to food as a consequence of sudden shocks (e.g. an economic or climatic crisis) or cyclical events (FAO, 2006). This dimension is increasing in importance with the economic and climate change-related challenges facing the world, especially developing countries.

Undernutrition, considered as insufficient energy uptake, is often accompanied by two additional problems, which are responsible of the increasing prevalence of diet-related non-communicable diseases (Development Initiatives, 2017):

(i) Malnutrition, or deficient intake of vital nutrients, such as iodine, vitamin A, iron and zinc, which affects about 2 billion people. The total cost of malnourishment is estimated to be worth of 3.5 trillion US dollars per year;

(ii) Overnutrition, suffered paradoxically by the same number of people, which are overweight (with a Body Mass Index over 25), 500 million of which are obese (with a Body Mass Index over 30); the global cost of overnutrition is evaluated to be around 2 trillion US dollars per year.

The phenomenon of overnutrition is particularly severe for industrialized countries, where more than 40% of people are overweight, but is increasingly relevant also for less developed countries. Nowadays, 88% of countries face a serious burden of either two or three forms of malnutrition. Nutritional problems are therefore multiple and intertwined, coexist in many geographical and pose challenges that require integrated responses.

The spectacular increase in global food production over the last few decades has often been achieved at the cost of overexploitation of the natural resources that form the basis of agriculture, putting at risk the sustainability of food production (Sonnino, 2014). Food security and nutrition policies therefore need to be complemented by active promotion of transition towards more sustainable food production systems. Additional challenges are posed by climate change and by the resultant extreme meteorological phenomena, altered rainfall regimes and modified pest, pathogen and weed distribution patterns.

The first section of this essay aims to critically analyze the global impact on natural resources of food production. The second chapter will examine the increasing and changing global food demand and the factors that are triggering its evolution. The third and last part of this paper will discuss the possible policy options to promote the transition towards more sustainable food systems.

Impact on natural resources

The global agricultural and food system has often overexploited or misused, and thus degraded and/or eroded, the natural resources upon which it depends, such as land, soil fertility, water, energy and biodiversity (Sonnino, 2014).

Agricultural land

The total area devoted to agricultural activities amounted in 2014 to 4.91 billion hectares, or 38% of the Earth's land surface, up from 4.46 billion hectares, or 34% of the Earth's land surface, in 1961. In other words during the last fifty years the agricultural frontier expanded at a rhythm of 0.19% per year, mostly at the expense of forests and other natural stands. For instance, an average 5.42 million hectares of forests have been chopped every year during the last twenty-four years, with the connected loss of biodiversity. Land use change is also responsible for 11% of the total greenhouse gases emission and therefore contributes substantially to climate alteration. From the opposite side, the phenomenon of land consumption for non-agricultural uses (urban expansion, infrastructures, industrial utilization) is increasingly eroding the arable land in many areas; this trend is expected to continue and eventually to accelerate during the next decades.

Soil fertility

According to FAO State of Land and Water, 33% of soils are highly or moderately degraded, with the consequent loss of fertility (FAO, 2011a). This is often the effect of unsustainable production practices, such as pasture and overgrazing, monoculture, excessive tilling, unsound water and nutrient management, and insufficient organic matter restitution. Costs of soil degradation were estimated to be as high as 40 billion dollars per year, without taking into account the hidden costs of increased use of fertilizers, loss of biodiversity and landscape deterioration.

Energy

The spectacular yield increases of the past decades have been made possible also by the abundant availability of relatively low cost fossil fuels that allowed for expanded agricultural mechanization and irrigation, for production of fertilizers and other chemical inputs, and for long-distance transport and storage of perishable foodstuff. Direct and indirect energy consumption of global food and agriculture systems, including food production, storage, processing and distribution, is equal to 95 exajoule per year, or 30% of the total energy consumptions. The direct energy consumption entails emission of 0.88 Gt of CO_2 equivalents (2012) and thus contributes to climate change.

Water

Among the natural resources that form the basis of food production, water plays a paramount role. Surface water covers 70.8% of the Earth, but fresh water is only 3% of the water present on our planet (Sonnino, 2014). At global level, renewable water resources are as big as 42,000 Km^3 (or 42 trillion litre) per year, 3,900 Km^3 (or 9%) of which are withdrawn. Agriculture absorbs 2,710 Km^3 per year, that means 70% of the total withdrawal. Similarly to what happens for land, the use of water for agriculture suffers from the increasing competition from other sectors (industrial use, civil utilization, etc.), especially in the areas where water resources are limited.

Irrigation is able to increase land productivity by two to three times (FAO and IFAD, 2006), while, in some areas of the world, irrigation is indispensable to grow any crop at all. The global irrigated area soared from 184 million hectares in 1970 to 324 million hectares, or 21% of total cultivated land, in 2012. The expansion of irrigation schemes, besides boosting productivity, contributed to enhancement of water management, and to prevention of droughts, floods and other natural disasters. Some countries, including in West and Central Asia, and North Africa, are withdrawing water at rates that are clearly not sustainable. Water overuse causes deepening of water bearing stratum, soil salinization and threat of exhaustion of water resources.

Biodiversity

Unsustainable agricultural practices contributed to genetic erosion, leading to loss of biodiversity at gene, species and ecosystem level (Lidder and Sonnino, 2012).

Out of 7,000 cultivated plants, about 900 are at risk of extinction and 14 are irreversibly extinct. Intraspecific variability is also under threat because of substitution of traditional varieties by few improved cultivars. Animal biodiversity follows a very similar trend: according to FAO, 20% of the 7,616 existing animal breeds are reported as at risk of extinction, while 690 are already extinct (FAO, 2007).

Biodiversity housed by forests is threatened by deforestation, forest diseases, pests and weeds, so that 50 per cent of the forest tree species are subject to genetic erosion (FAO 2014b). Soil biodiversity, namely microorganisms and invertebrates, is equally under threat because of a number of factors, including the incorrect use of pesticides.

Food losses and waste

There is wide consensus about the high relevance of food losses and waste to food security and sustainability of agrifood systems and about the need to reduce them. The study by Gustavsson *et al.* (2011) assess global food losses and waste at a level of roughly one third of the mass of edible parts of food intended for human consumption, or 1.3 billion tons per year. In other words the produce of roughly 1.4 billion hectares is lost or wasted instead of being eaten.

The distribution of the losses and waste along the production chain depends largely on the product and the geographic region. While in low-income countries food is mostly lost during agricultural and post-harvest phases, due to infrastructural weaknesses, in middle- and high-income countries food is mostly lost during distribution or wasted at consumption level, mostly due to incorrect consumers' behaviours.

Evolution of global food demand

The global food demand dramatically increased during the last decades, as a result of rapid population growth, and radically changed its composition, mostly because of changes in dietary habits in emerging countries. In particular, the consumption of animal-derived food in some developing countries rose so rapidly as to suggest the adoption of the term «livestock revolution» (Delgado, 2003). For instance, between 1961 and 2005 per capita consumption of eggs increased by 5 folds, meat by nearly 3.5 folds, milk almost doubled (FAO, 2009).

There are at least five intimately intertwined triggers that will modify size and composition of food demand during the next decades: (i) population growth, (ii) urbanization, (iii) income growth in emerging countries, (iv) population ageing, and (v) improvement of average education level. This section will briefly discuss these factors and their possible consequences.

(i) *Population growth*: The world's population is projected to increase to over 9.6 billion people by the year 2050, and nearly all of this increase will occur in developing countries (UN Population Division, 2014). According to the World Resources

Institute (WRI, 2013), the global demand in 2050 will reach the level of 16,000 trillion kilocalories per year (calculated as crop calories, which includes crops for direct human consumption, animal feed, industrial applications, seeds, and biofuels).

(ii) *Urbanization*: Population shift from rural to urban areas causes profound socio-cultural transformations. Urbanized populations, including relatively poor people, have better access to processed food and are more exposed to advertisements for foods rich in fats and sugars than people living in rural areas (Foresight, 2011), and can therefore be prone to change their dietary habits. The United Nations projected that by 2050 about two thirds of the global population will inhabit urban areas (Figure 2); in 2010 half of the world's populace was urbanized (UNDESA, 2014).

(iii) *Income growth in emerging countries and in many developing countries*: According to van der Mensbrugghe *et al.* (2011) the GDP of the developing countries is projected to grow 9.8 times between the year 2005 and 2050, corresponding to a 6.6-fold increase in average per capita income. The incidence of poverty (percentage of people living on less than 2 USD per day) in developing countries fell from 69.1% in 1988 to 51.2% in 2008; the incidence of extreme poverty (percentage of people living on less than 1.25 USD per day) also fell in this same period, from 45.1% to 27% (IFAD, 2010). This progress is mostly due to a massive reduction of poverty in East Asia and emerging countries in other areas, and is likely to keep the same pace during the next decades. Households that improve their incomes initially tend to increase the amount of food consumed, even if less than proportionally, according to the Engel's law of consumption (Foresight, 2011). Subsequently they tend to modify their diets, increasing the consumption of more expensive products, such as sugars, fats and animal-based foods, which require considerably more resources to be produced than staple food (Gouillou and Matheron, 2011; HLPE, 2014b).

(iv) *Population ageing:* In 1950 on a global level, there was 1 individual aged 60 years or over out of 12 people and 1 person aged 65 or over out of 20 people. By the year 2000, the ratio of persons aged 60 years or older had increased to 1 in every 10, while there was 1 person aged 65 or more in 14 people. The projection for the year 2050 foresees that more than 20% of world's population will be aged 60 years or over, while nearly 15% is projected to be at least 65 years old (UNDESA, 2001). More aged people tend to prefer food that they perceive as healthier.

(v) *Improvement of average education level*: The proportion of the population (over 15) that has a junior secondary or higher education is projected to be substantially the same for female and male in 2050 and to surpass the level of 80%, while the values in 2010 were as high as 67% for men and lower than 60% for women (Lutz and Samir, 2010). Educated people tend to be more conscious in their food choices.

Food preferences are also influenced by cultural, religious and social factors (Harris, 1985) that differ greatly between and within countries. A more numerous, more urbanized, wealthier, more aged, and more educated population will tend to increase their food consumption and to change the composition of their diets. World food demand is estimated by FAO to expand by 50% and to change composition between 2013 and 2050 (FAO, 2017). Two-thirds of the expected growth of global demand for food and nutrition will be caused by demographic growth and the remaining one-third by the increased average purchasing power (WRI, 2013).

Options for sustainable food systems

To satisfy the soaring global food demand and at the same time limit the pressure that agricultural production systems pose to natural resources, in the context of climate change, is a challenge of unprecedented dimensions and nature. A profound transformation of food and agriculture systems is therefore required to make them sustainable, more productive and more responsive to nutritional needs at the same time. In other words, a paradigm shift is needed to reposition the global food and agriculture system from being an important driver of environmental degradation to being a key contributor to the global transition to sustainability. Agenda 2030 and the Sustainable Development Goals, primarily the SDG 2 «*End hunger, achieve food security and improved nutrition, and promote sustainable agriculture*», offer the conceptual framework for such transformation (Sonnino and Stefanova, 2018; Caron *et al*., 2018).

The possible policy options are summarized in table 1. The efficiency of production option relies on technological optimization to boost food offer and thus meet the growing demand, addressing at the same time the negative externalities. There is a wide consensus that production increase can be achieved mainly by increasing yields, limiting the expansion of cultivated land at the expense of forests and other natural stands. Sustainable intensification of agricultural production systems, recommended by several studies as a possible solution (The Royal Society, 2009; Ringler *et al*., 2014), requires the development, the dissemination and the adoption of agronomic practices that optimize resource use efficiency and prevent externalization of environmental costs. Sustained investments and strengthened capacities to innovate, including research and extension, are essential to achieve this objective (FAO, 2014a; Aerni *et al.*, 2015). Huge improvements in agricultural productivity can be achieved by closing the yield gaps between the observed yields and those potentially attainable in a given region (Mueller *et al.*, 2012), and, in particular, the yield gaps between advanced farms and less efficient farms. In this respect, access to knowledge, education, technologies, credit, markets, technical assistance and other services, plays a pivotal role to assist smallholders and upgrade the productivity of their farms. Once more, sustained investments and capacity development are critically needed to make rural advisory services more effective and more efficient.

The second policy option is inspired by a more pessimistic view and is focused on demand restraint. The most promising option related to reduction of food demand is the cut of food losses and wastes along the entire food chain (HLPE, 2014). Wider adoption of balanced diets and reduction of over-nourishment should be promoted to

Policy option	*Value judgement*	*View*	*Key strategy*
Efficiency of production	Producers' responsibility	Optimistic	Technological optimization
Demand restraint	Consumers' responsibility	Pessimistic	Sustainable consumption
Food system transformation	Social equity + system responsibility	Balanced	Systems approach

Table 1. Policy option for matching of food supply and demand.

improve the health status of obese and those who are overweight, but the actual contribution to reduction of global food deficit would not be very significant. Meat-intensive diets are based on production systems that are less efficient than crop production systems. A reduction in the share of animal-based food in daily diets could therefore free-up for direct human consumption part of the agricultural production currently utilized for animal feed. The factors that triggered the livestock revolution persist, and meat consumption is expected to continue to increase along with the increasing income levels, even if demand increase in industrialized countries is attenuated by healthy concerns (Steinfeld *et al.*, 2010). It is therefore unlikely that a redirection from diets rich in products of animal origin towards vegetarian diets can significantly reduce the projected food deficit. The demand of animal products can be shifted towards a more efficient mix, taking into consideration that beef is a far less efficient source of calories and proteins than milk, eggs and other meats. Its substitution with other equally nutritious animal products could significantly reduce the number of hectares devoted to animal feed production and the related environmental footprint (WRI, 2013). Any intervention on diet composition should, however, also take into consideration that consumers' preferences are determined not only by sustainability considerations, but also by traditional habits, cultural believes and religious prescriptions.

Both policy options identify important issues and indicate possible ways out, but do not seem to offer comprehensive responses to present and future challenges. A more integrated approach is offered by the «food system transformation» strategy. In its report on food losses and waste, the *High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security* adopted the following definition of a food system: «*a food system gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the output of these activities, including socio-economic and environmental outcomes*» (HLPE, 2014). The food system transformation policy option considers production and consumption patterns at the same time, addressing also the social and economic inequalities. Such a systemic transformation can only happen through both generation of new knowledge and enhanced translation of knowledge into use (FAO, 2017).

Unrelatedly to the policy options, gender equity plays a pivotal role for sustainability of agrifood systems: ensuring equal access to education, services, civil rights, credit, technical assistance and political life does not respond only to ethical principles, but would have several relevant consequences on both food demand and supply. A FAO report estimates that, if women could have the same rights as men, the productivity of their farms would increase by 20-30%. The total agricultural production of developing countries could rise up to 4% (FAO, 2011b). Similarly, a more equity for disadvantaged and vulnerable people, including indigenous communities, would have positive effects on the sustainability of agricultural production systems.

Concluding remarks

As discussed above, a dramatic transformation of agrifood systems is needed to make them sustainable and able to feed the world. This transformation requires a consistent injection of a considerable amount of new knowledge and enhanced transformation of this knowledge into economic social and environmental value (FAO, 2017). This translates in three major needs: sustained investments in research and innovation; research that integrates many very different disciplines and perspectives in a systems' perspective; and to do so in such a way that decision-makers, at all levels, from government to farm, can mobilize knowledge to address multiple objectives, decide on priorities, and identify and manage synergies and trade-offs. The prevailing reductionist approach in food and agricultural research, characterized by fragmentation of academic disciplines, tendency to overspecialization and focus on only single phases or issues along the food chain at a time, should be abandoned. Sustainable food system transformation cannot be described or planned using exclusively linear functions, while neglecting multiple interdependencies and interrelations among food chain actors, supply and consumption, urban and rural areas as well as agriculture and the environment (Sonnino and Stefanova, 2018). The complex and dynamic nature of food systems require the adoption of a system thinking, which integrates different disciplines and perspectives; does not single out the system's components, but analyses the complex interplay among them; consolidates local, traditional and formal scientific knowledge; and establishes indicators for the change. In addition, co-ownership of research programs by the various categories of users and stakeholders must be ensured and participatory research processes should be facilitated, from their beginning, if we want to avoid that research results remain locked in the so-called «death valley».

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