Part Two

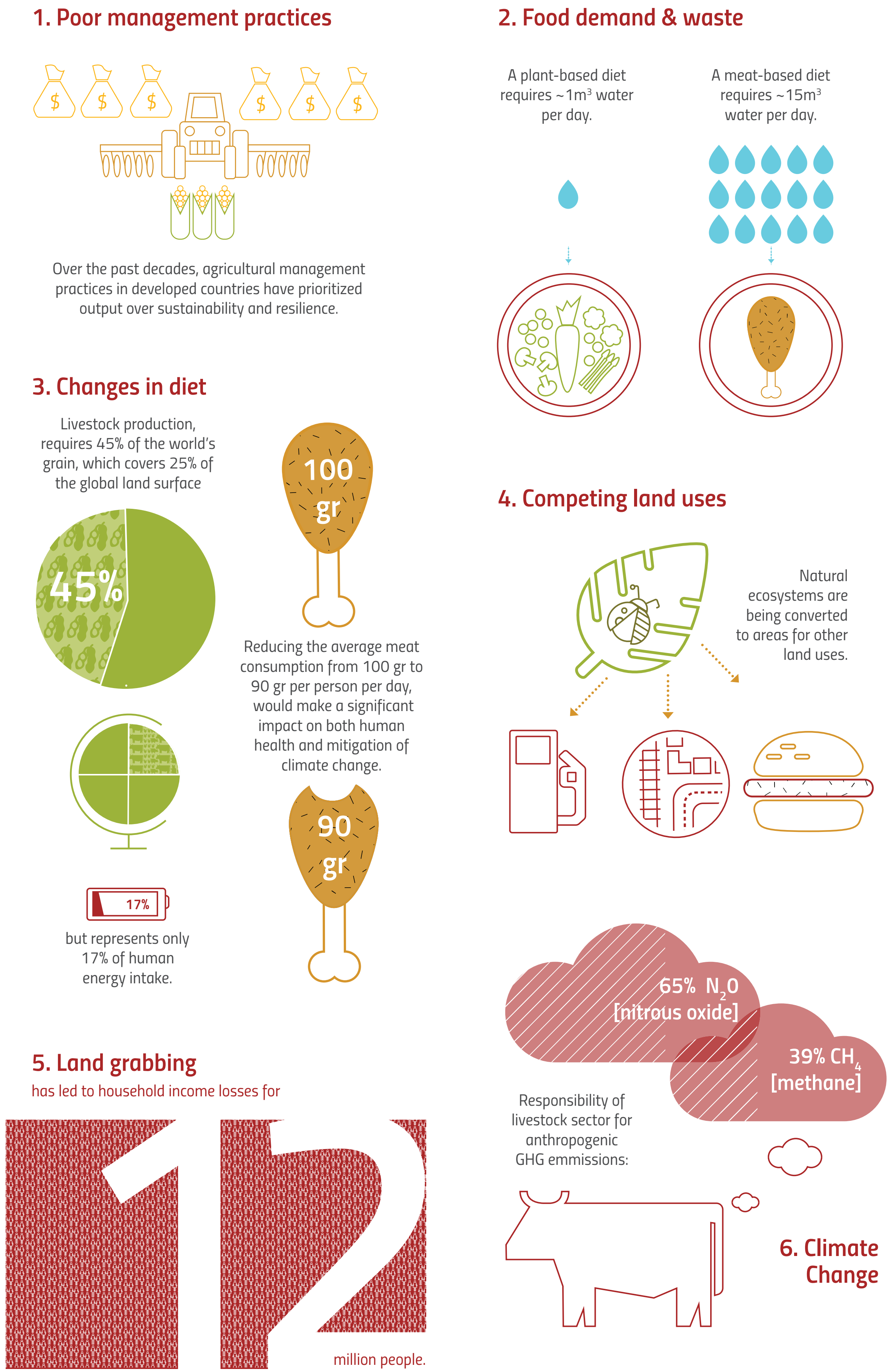
CHAPTER 7

FOOD SECURITY AND AGRICULTURE

Agriculture and livestock cover over one-third of the world's land surface, dwarfing all other land uses. Intensification, driven by a lucrative but largely inefficient food system, has boosted production. However, it has also disturbed cultural landscapes, sustained over thousands of years, and accelerated land and soil degradation, water shortages, and pollution. Agricultural expansion is hastening the loss of species and natural habitats. In spite of production increases, we are now experiencing widespread food insecurity in what should be a world of plenty.

Proven and cost-effective alternatives to minimize these impacts already exist. Overall, agriculture needs to be more effectively integrated with other land use sectors. Multifunctional approaches to food production are needed, recognizing that land provides many other vital services. Key elements include increasing productivity and nutritional values from a given area of land, reducing offsite or downstream impacts on the environment, and promoting more local production, less land-intensive diets, and a reduction in food waste.

Figure 7.1: Competing pressures on agricultural land



INTRODUCTION

Agriculture is the single biggest land use covering more than one-third of the world's land surface, not including Greenland and Antarctica. Much of the best land is already under cultivation and much of what is left is too high, steep, shallow, dry, or cold for food production.[1] The amount and quality of land available for food production is under pressure from the decisions and demands made by consumers, producers, and governments. The most significant pressures on land resources used for food production include:

1. **Poor management** practices resulting in suboptimal yields, due mainly to resource use inefficiencies associated with irrigation, fertilizers, livestock, crop selection, etc.
2. **Food demand** and waste which is increasing rapidly with population growth, increased incomes, and globalization.[2]
3. **Changes in diet** further drives agricultural expansion as consumers increasingly demand food that is land-intensive, particularly processed foods and meat.[3]
4. **Competing land uses** reduce the area available for food production,[4] including for biodiversity and ecosystem services, urbanization,[5] infrastructure, tourism, and energy as well as biofuels[6] and other non-food crops.
5. **Land grabbing** and virtual natural resource trading undermine food and nutritional security as well as smallholder tenure and resource rights in poor and vulnerable communities.
6. **Climate change**, which is expected to reduce crop yields in many countries resulting in greater food insecurity.[7]

These and other pressures are squeezing a finite resource that is rapidly reaching its limits. Land scarcity is already of serious concern[8] and there is a growing consensus that our remaining forests and grasslands need to be left intact for their biodiversity, carbon stores, and other essential ecosystem services. Some speak about a food, energy, and environment "trilemma," where food and energy compete for land causing further damage to the environment.[9] Maximizing the productivity of land without undermining its associated ecosystem services, often referred to as sustainable intensification, is one of the greatest challenges of the 21st century.

Sustainable Development Goal 2 aims to "*End hunger, achieve food security and improved nutrition and promote sustainable agriculture*" and by way of SDG target 2.4, "*ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality*."

In 1996, the World Food Summit agreed that: "*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*."[10] This also implies that food supply is sustainable in the long run, and that agriculture does not undermine the provision of ecosystem services or overstep the ecological boundaries.

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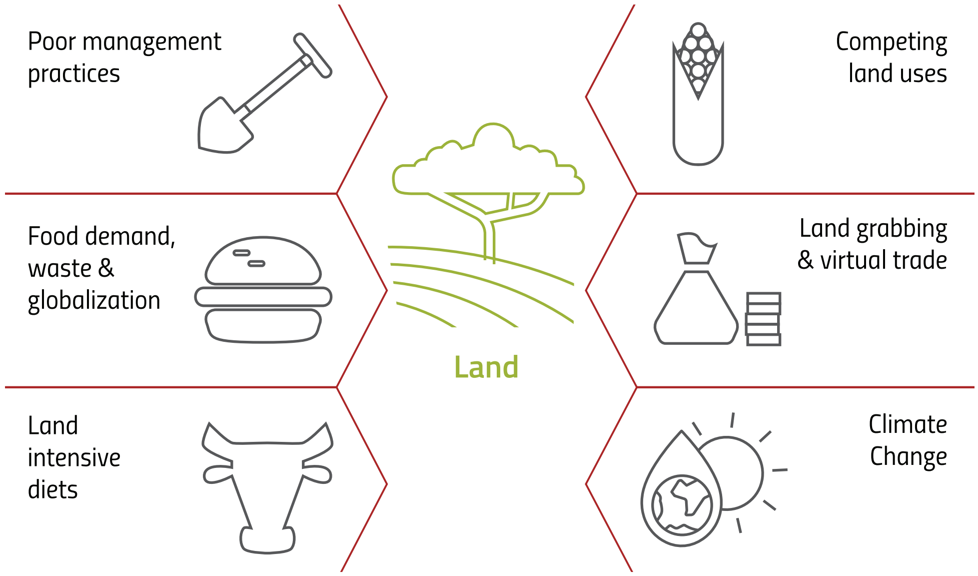
Figure 7.2: Competing pressures on land resources



1. Poor management practices

Over the past few decades, agricultural management practices in developed countries have prioritized short-term productivity over long-term sustainability and resilience. The "green revolution" in the 1970s promoted high-yielding varieties of crops, such as rice, which relied on increased inputs of mainly chemical fertilizers and pesticides. The result has been a much-needed boost in food production but also an accumulation of long-term problems with soil and human health, increases in crop pests and diseases, offsite pollution, and the loss of genetic diversity. At the same time, agriculture in parts of the world that have not adopted modern practices remains inefficient and can also inhibit the long-term sustainability of the food production system.

Swidden or slash and burn agriculture relies on the clearance and burning of forests or grasslands to open up space for crops. After a few years of cultivation, soil productivity declines and weed pressure increases, forcing farmers to clear new areas. Swidden can be sustainable if a small fraction of the landscape (less than about 5 per cent) is cleared and abandoned in any given year, but the cycles become more frequent when the population of farmers increases and space becomes scarce. This can lead to more or less permanent land degradation with forest often changing into low productivity shrubland or grassland.[11] Similarly, the stocking of animals beyond the carrying capacity of the land results in overgrazing and declines in the health of rangelands.[12]

While it is hard to generalize, it seems that overall farming has become more productive but less sustainable in the last few decades,[13] and is now exceeding planetary boundaries for stressors such as nitrogen levels in the ecosystem.[14] Poor management practices are generally not driven by ignorance or irresponsibility but by larger political, economic, and demographic pressures that give farmers little choice.

2. Food demand and waste

Concerns about food security are growing as the global demand for food will likely surpass supply in just a few years. The world currently has more than sufficient agricultural land to feed its population yet economic and distribution challenges still leave large numbers of people hungry and malnourished. If these challenges remain in the near future, demand will likely overtake our ability to increase net production.[15] Some suggest that the world can feed 10 billion people on the current area of agricultural land.[16] Others argue that even if annual increases in major crop yields follow recent trends, food production will still fall short of the 70 per cent increase estimated to be required to feed 9 billion by 2050.[17,18,19] Furthermore, due to increased consumption of animal protein, demand for both meat and crop-based livestock feed (mostly cereals and soy) is expected to rise by almost 50 per cent by 2050.[20]

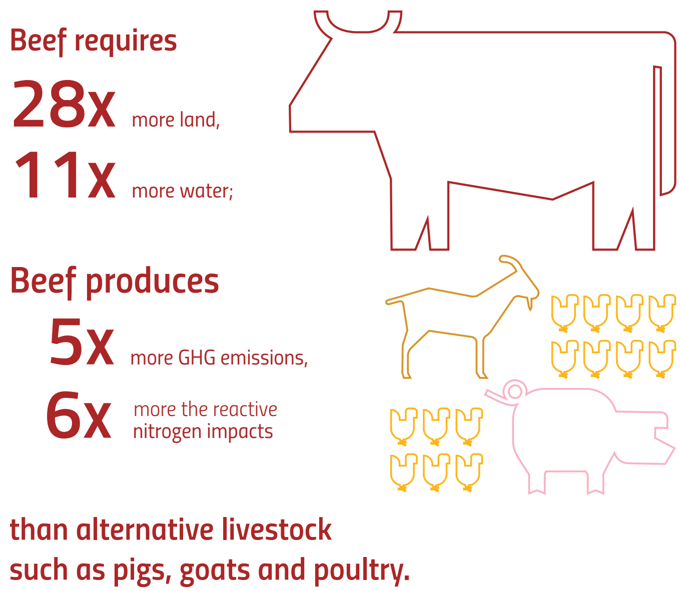


Figure 7.3: The case of beef

One reason that the world faces such grave pressures on land resources is the startling inefficiencies in the way that we produce and consume food. It is estimated that one-third of all food produced is wasted: this is equivalent to 1.3 Gt of edible food every year, grown on 1.4 billion hectares of land (an area larger than China). Annual food waste is also the waste of 250 km^3 of water and USD 750 billion (equivalent to the GDP of Switzerland), and has a cumulative carbon footprint of 3.3 Gt of CO_2 equivalent per year, making food waste the third largest emitter after the United States and China.[21]

Eliminating food waste would reduce the projected need to increase the efficiency of food production by 60 per cent to meet expected demands by 2050.[22] Other studies have estimated even greater losses with up to half of all food produced being wasted.[23] Hotspots of food waste include the industrialized parts of Asia for cereals, fruit, and vegetables, Europe for fruit and vegetables, and Latin America for fruit; high income regions also waste more than two-thirds of meat produced.[24]

The drivers of food waste vary: in poor countries, this is primarily due to lack of capacity to store and transport food early in the process, while in wealthy nations, it is caused mainly by retail marketing decisions, consumer profligacy, and the inefficiencies of mass production towards the end of the food supply chain. In 2005, it was estimated that 25-50 per cent of the total economic value of food was lost during the process of transport and storage because of reduced quality.[25]

Lack of refrigerated transportation, poor roads, and inclement weather combine to generate high levels of food waste in many tropical countries, and poor storage is identified as a major contributing factor to spoilage in many former Soviet countries, such as Ukraine.[26] In China, around 8 per cent of grain is lost during storage, 2.6 per cent in processing and 3 per cent in distribution; a combined annual total of 35 million tons.[27] In many developed countries, consumer and retail food waste is exacerbated by the rejection of misshapen or blemished but perfectly edible fruit and vegetables, short sell-by dates, and bulk offers that encourage over-purchasing. In the United States, about 70 million tons of edible food is wasted every year.[28] With almost 1 billion people now categorized as obese, the excess consumption of food is now considered by some as a form of food waste.[29]

3. Changes in diet

Land scarcity and food insecurity are made worse due to the growing demand for meat and other land-intensive foods, such as processed foods using soy and palm oil, which are an inefficient and unhealthy way of addressing human nutritional needs. Global meat consumption has virtually doubled since the 1960s,[30] and its production requires about five times more land per unit of nutritional value than its plant-based equivalent.[31] The production of animal products has dominated agricultural land use change, expansion, and intensification over the last half century.[32] Similar disproportions exist with regard to water use: average water use for maize, wheat, and husked rice is 900, 1,300, and 3,000 m^3 per ton respectively; while that for chicken, pork, and beef is 3,900, 4,900, and 15,500 m^3 per ton.[33]

The resource use inefficiency and environmental footprint of livestock production is of less concern if animals live entirely or mainly by grazing on natural vegetation in areas unsuitable for crop production. In many instances, livestock help maintain semi-natural habitat and provide valuable protein.[34] The costs, in terms of lost biodiversity and ecosystem services, rise dramatically if forest or woodland is cleared to create pasture as has been the case for much of the new grazing lands in Latin America.[35] If livestock is kept indoors or in enclosures, relying on feed grown elsewhere, the land required increases even more. While industrial livestock production can be an economically efficient way of producing large quantities of animal products, it is a very inefficient way of converting solar energy to nutrient-dense food for humans.

Box 7.1: The case of beef

Out of all the livestock produced, beef is by far the most costly in terms of its inefficiency and impacts on land use and pollution, requiring an order of magnitude more resources than other types of livestock. On average, beef requires 28 times more land and 11 times more irrigation water; it produces five times the greenhouse gas emissions and six times the reactive nitrogen impacts than alternative livestock such as pigs and poultry.[42] There is little dispute that reducing beef consumption would have an immediate and positive impact on both food security and greenhouse gas emissions.[43]

Inefficient beef production also drives land use change. In Queensland, Australia, woodland clearance mainly for cattle pasture averaged 300,000-700,000 ha per year through the 1990s[44] until a ban on further clearance in 2006. The ban reduced woodland losses dramatically but was subsequently relaxed in 2013 after opposition from farming groups. Along with the loss of natural vegetation, the resumption of clearing continues to dramatically reduce ecosystem services in the region. For instance, surface runoff has increased 40-100 per cent due to deforestation. According to the latest analysis of satellite data (2015-16) undertaken by the Australian National Inventory System, conversion of primary, mature forest to other land uses has been reduced by 90 per cent from levels of 1990 and now sits at about 56,000 hectares. The level of clearing of primary forest has been relatively constant in recent years (regardless of regulatory changes).The majority of clearing of forests - about 85 per cent in 2015 relates to re-clearing (secondary forest) on previously cleared land. The regrowth of secondary forest is currently outstripping the re-clearing activity – in 2015, in net terms, there was a net increase of 225,000 hectares of secondary forest on lands previously cleared for grazing. While over 40 per cent of Queensland's cropland is devoted to producing cattle feed, additional imported feed is still required.[45]

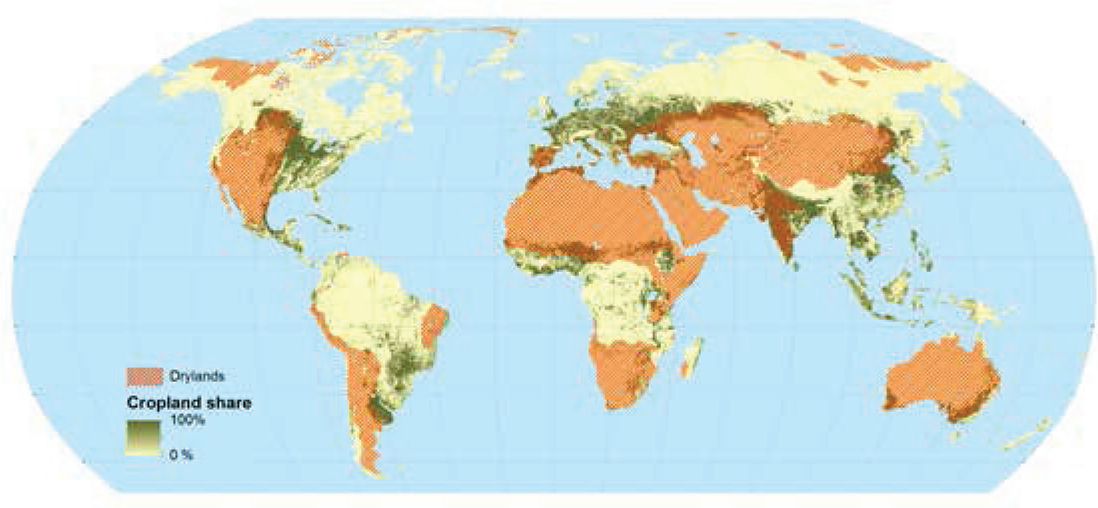
When the amount of land used for grazing and feed crops is combined, livestock production accounts for around 70 per cent of agricultural land[36] and is perhaps the single largest driver of biodiversity loss and reduced ecosystem services. Using crops historically consumed only by humans to feed livestock, such as cereals and legumes, directly increases consumer prices, undermines local food security, and indirectly drives further land use change.[37]

The global market for animal products is booming. Between 1967 and 2007, pork production rose by 294 per cent, eggs by 353 per cent and poultry meat by 711 per cent; while, over the same period, the relative costs of these products declined.[38] Projections for sub-Saharan Africa suggest a tripling of milk consumption by 2050, particularly in East Africa, and that the consumption of meat from poultry and pork, and eggs, could increase by six times in West Africa and four times in Southern and East Africa.[39] Along with changing diets associated with higher incomes, cheap feed crops (particularly soybeans) have been a huge factor contributing to increased meat production. Today, most pigs and poultry are kept indoors and rely solely on protein-rich feed and pharmaceuticals to enhance growth,[40] raising sustainability, environmental, and animal welfare concerns. Currently, 36 per cent of calories produced by the world's crops are diverted for animal feed, with only 12 per cent of those feed calories ultimately contributing to the human diet as meat and other animal products. This means that almost a third of the total food value of global crop production is lost by "processing" it through inefficient livestock systems.[41]

Livestock production is also a major cause of climate change, producing an estimated 7.1 Gt CO_2-eq per annum, or approximately 14.5 per cent of anthropogenic greenhouse gas emissions. Feed production and processing, along with enteric fermentation from ruminants (releasing methane), are the two main sources of emissions; beef and cow milk production contribute 41 and 20 per cent of the sector's emissions respectively.[46] Modeling the impacts of projected increases in livestock production found that by 2050 greenhouse gas emissions from meat, milk, and egg production could increase by 39 per cent.[47] Average global meat consumption is currently 100 grams per person per day; even reducing this to 90 grams per person per day would make a significant impact on both human health and GHG emissions.[48]

Over the past five decades, human diets have moved toward a greater consumption of processed foods that are low in essential nutrients and contain a high percentage of refined sugars, oils, salt, and fats.[49] Common factors driving this are more processed foods, access to cheaper foods, and aggressive marketing of some of the unhealthiest foodstuffs.[50] Major food outlets base their profits on selling large amounts of high-fat, high-protein foods which, if consumed regularly, lead to obesity,[51] a problem now impacting virtually every country in

Figure 7.4: Global cropland (green shaded area) occupies about 14 per cent of the ice-free land of the Earth[63]



the world.[52] Based on recent average annual dietary changes and the contribution of palm and soybean oil to vegetable oil consumption and yields, this will result in converting an additional ~0.5 to 1.3 million hectares of land to oil palm plantations, and ~5.0 to 9.3 million hectares to soybean plantations by 2050.[53] Much of this expansion will occur at the expense of tropical rainforests, unless strict land-use regulations and market initiatives are implemented to avoid deforestation.[54]

There are significant costs associated with the expansion of oil-palm plantations into tropical rainforests in Indonesia. This sometimes entails the draining of peatlands, which can then catch fire. The resulting health risks from air pollution are severe, especially for children and older people. According to the World Bank, the disruption to economic activity in 2015 alone cost the Indonesian economy an estimated USD 16 billion — more than the annual country-wide value added by palm oil.[55] Peat drainage has a huge carbon footprint: the lowering of the water level in the peat meadow system of the Netherlands is comparable to average emissions from 2 million cars.[56]

4. Competing land uses

The demand for food (including more meat and processed foods), urban and infrastructure development, and biofuels will have a growing impact on overall land availability. The world's ice-free land area is estimated at 13.2 billion ha with 12 per cent (1.6 billion ha) currently used for the cultivation of agricultural crops, 28 per cent (3.7 billion ha) under forest cover, and 35 per cent (4.6 billion ha) composed of grasslands and woodland ecosystems, much of which is used for grazing and equivalent to at least twice the cropland area.[57]

The global area of cultivated land has increased by around 12 per cent in the last few decades,[58] or 159 million ha since 1961, much of which has been converted from natural ecosystems.[59] Croplands occupy about 14 per cent of the total ice-free land area while pastures occupy about 26 per cent.[60] Approximately 44 per cent of the world's agricultural land is located in drylands, mainly in Africa and Asia, and supplies about 60 per cent of the world's food production.[61] Most of the new agricultural land has come from the destruction of natural forests; from 2010 to 2015, tropical forest area declined by 5.5 million hectares a year.[62]

Future projections suggest that satisfying global food demand means more land will need to be converted.[64] Future cropland expansion will not be evenly spread. One estimate found that by 2050, 55 per cent of the projected expansion will occur in Africa and the Middle East, 30 per cent in Latin America, and just 4 per cent in Europe.[65] Competing land uses frequently involve trade-offs between production needs (i.e., provisioning services) needs and those of biodiversity, native forest dwellers, and the supporting and regulating services that natural habitats provide.

Food production is a critical driver, particularly of tropical forest loss,[66] where forests were the primary source of new agricultural land throughout the 1980s and 1990s,[67] and continue to be converted to new pasture[68] and farmland today. An analysis of the 11 most critical deforestation fronts found agriculture to be the dominant, and usually the largest, driver of land use change.[69] Furthermore, the type of agriculture is changing from small-scale, peasant farming to large-scale, ranching and monoculture plantations.[70] Soybean[71] and oil palm[72]

Box 7.2: The rapid expansion of soybean cultivation

Soy or soya (*Glycine max*) is an annual legume grown for its edible bean. Over recent decades, soybean has undergone the fastest expansion of any global crop, resulting in the conversion of forests and other important natural ecosystems. Soy is highly attractive to the food industry as it produces more protein per hectare than any other major crop[95] and has become a key part of the global food supply, particularly as livestock feed. In fact, three-quarters of the global harvest is used for feed, primarily for poultry and pigs, especially in China.[96] Soybean is also becoming an increasingly important source of biofuels.[97]

In the last 50 years, the area of soybean planted has grown tenfold, to over 1 million km^2: the total combined area of France, Germany, Belgium, and the Netherlands. Around 328 million tons are expected to be produced in 2016/17,[98] with the bulk of the production coming from Brazil, the United States, Argentina, China, India, and Paraguay.[99] Millions of hectares of forest, grassland, and savanna have been converted, either directly or indirectly, as a result of this global boom.[100] The fastest growth has been in South America, where the area of land devoted to soybean increased from 17 million hectares in 1990 to 46 million in 2010, mainly at the expense of natural ecosystems. Conversion is not always direct; land cleared initially for cattle pasture is then planted with soybean.[101] Land use change also results in significant social disruption. Soybean production has been implicated in the eviction and displacement of indigenous communities in Argentina[102] and Paraguay.[103] The boom is far from over: it is estimated that soybean production will continue to grow, almost doubling by 2050,[104] not counting the potential for further expansion due to biofuel demand.

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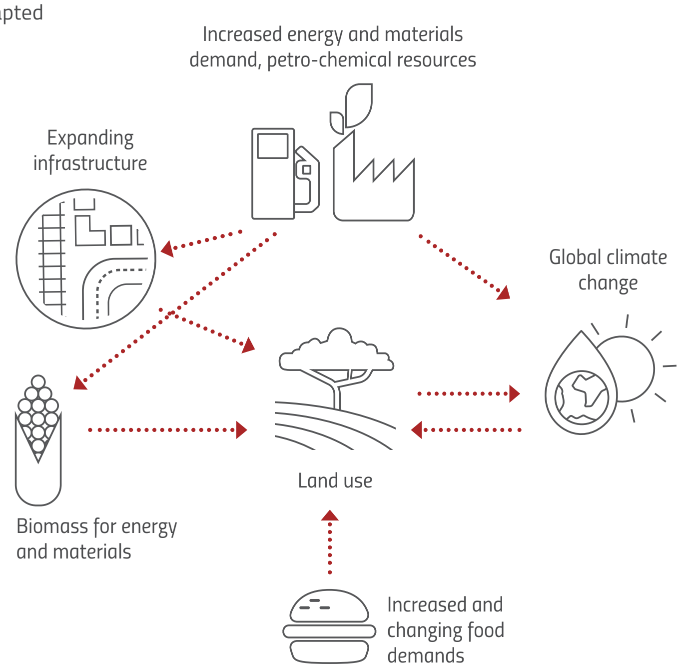
have dramatically increased in terms of area planted and biofuels are beginning to escalate competition for scarce land.[73] Urban population growth is more closely correlated with deforestation than that of rural population growth, pointing to the critical role that urban demands for food and fiber have in land use change for agriculture.[74]

Figure 7.5: The new competition for land, interactions and feedbacks: Adapted from[134]



Deforestation in South America is driven primarily by commercial agriculture[75] and large-scale ranching,[76] predominantly cattle;[77] this trend is fueled by low feed prices[78] with many farms planting exotic African grasses.[79] The expansion of plantation agriculture is also important, particularly for animal feed[80] and biofuels,[81] such as soybean,[82] oil palm,[83] and other crops[84] with its production often linked to subsidized resettlements.[85] Indirect land use change is also occurring,[86] for example, when soybeans replace pasture[87] forcing cattle ranchers to move into new areas of forest.[88] In Africa, peasant agriculture and tree cutting for fuelwood and charcoal production remain the dominant agents of change, such as in the Congo Basin[89] where an estimated 90 per cent of wood harvested is for fuel.[90] In southern Africa, 80 per cent of farming is small-scale[91] including resettlement in rural areas in post-conflict Angola[92] and increased tobacco production in Malawi.[93] The growth in plantation and biofuel crops for the export market is also occurring, particularly in Mozambique.[94]

In Asia, plantation agriculture, often preceded by logging, is the most important driver of land use change, although there are large regional differences. Conversion for oil palm is the biggest cause of deforestation across Indonesia,[105] with areas still expanding,[106] and rubber plantations also increasing.[107] The conversion of primary and secondary forest for food and non-food crops, including sugar, rice, rubber,[108] and biofuels[109]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is increasingly prevalent in the Mekong Basin. Political changes in Myanmar are rapidly fueling land use change,[110] with over 2 million hectares of forest allocated for conversion to agriculture.[111] Conversely, while plantations are emerging in Papua New Guinea,[112] small-scale agriculture remains the largest driver of land use change.

The expansion of agricultural land in many developing countries has only led to marginal increases in livestock production. Livestock systems in these situations are often low-input and relatively inefficient; productivity is often further reduced by land and soil degradation.[113]

The challenges associated with fossil fuels, including both their finite nature and pivotal role in climate change, has stimulated the search for alternative energy sources. Natural forests and timber plantations supply biomass that can be processed for use in domestic stoves, combined heat and power stations, and as a feedstock for liquid fuels,[114] with one global estimate of potential from logging and processing waste being 2.4 billion m^3 per year.[115] Crops, such as soybean and palm oil, are increasingly being processed into fuels, reducing their availability as foodstuffs. Crop calories used for biofuel production increased from 1 to 4 per cent between 2000 and 2010.[116] In Argentina, soybean biodiesel production reached 2.7 million tons in 2016, 50 per cent more than the previous year. Argentina is expecting to resume soybean exports to Europe following a court ruling that ended anti-dumping duties,[117] and soybean oil is projected to supply about 10 per cent of the European Union's biofuel production by 2020.[118]

Advocates of plant-based energy alternatives argue that if food system efficiencies could be further increased, then substantial biofuel production would be possible without impacting food security.[119] This is based on the assumption that biofuel crops will be predominantly grown on degraded land, land not suitable for agriculture, and land made available by intensifying livestock production and thus "freeing up" land.[120] However, in practice today, most biofuel crops are grown on fertile soils, usually with serious negative social and environmental impacts, which threaten to lock in some of the best agricultural land for energy production.[121] Other concerns focus on the amount of natural forest cleared for biofuels,[122] which includes indirect land use change;[123] loss of biodiversity;[124] the long-term effects of tree plantations on soils and hydrology;[125] the impacts of intensifying crop production by using agrochemicals;[126] the social consequences of a rapid increase in biofuels[127] and potential for increased inequality;[128] and the effect on the overall carbon balance.

Although a highly efficient biofuel energy system could in theory help reduce carbon dioxide emissions, clearing natural vegetation can result in a carbon pulse that could take decades to recapture. For example, it would take an estimated 420 years of biofuel production to replace the carbon lost from clearing peatland forests,[129] thus compounding the impacts on biodiversity and climate.[130] A major switch to biofuels could easily have unintended climate consequences through land use change and agricultural intensification.[131] Biofuel expansion in productive tropical ecosystems will always lead to net carbon emissions for decades or centuries while increased biofuel production on degraded or abandoned agricultural land could provide an almost immediate net reduction in carbon emissions.[132] Guidance on sustainable production practices is starting to emerge,[133] yet the question of how much land can be used sustainably for biofuels remains contentious and the potential negative impacts are increasingly recognized.

5. Land grabbing and virtual land trading

As land becomes in shorter supply, poor small-scale farmers generally lose out as more powerful players gain control over a larger proportion of what remains. "Land grabs" are a growing phenomenon in Central and South America, Africa, and southeast Asia. The term refers to the acquisition, by outside interests, of the rights to harvest timber or establish large-scale commercial farms, plantations, or livestock operations often on lands where tenure has historically been communal or customary.[135] The exact size and number of global land grabs is not known, since many transactions are conducted without public notice and against the will of local people.[136] Land grabs increase tensions and the potential for conflict within communities and between affected groups and the governments that facilitate the process.[137]

Concern is mounting about the impacts of these large-scale acquisitions on food security, hydrology, land use change,[138] including deforestation,[139] and losses in rural employment opportunities.[140] Although land grabs still represent a small proportion of total agricultural land, they tend to control the most productive land usually with the most developed infrastructure and transportation links.[141] A more detailed discussion of land grabs and tenure security is contained in Chapter 5.

When a government undertakes major resettlement programmes or displaces communities for development projects, the results can be the same as a land grab. On the grasslands of Inner Mongolia and Tibet, governments have actively resettled pastoralists and rural populations to towns or other rural areas to free up land for development projects, often citing overgrazing as a reason and with mixed results in terms of their welfare.[142] The Three Gorges dam project in China, completed in 2012, flooded 600 km^2 of land and displaced an estimated 1.3 million people who were relocated to other rural areas and urban centers within the same region as well as to other provinces of China.[143]

About one-fifth of global cropland area, and its associated water use, produces agricultural commodities that are consumed abroad. Export demand is one of the leading drivers of cropland expansion.[144] The physical separation of production and consumption has implications for both the exporting and importing countries. Associated environmental burdens of food production are shifted disproportionately to export producing regions, undermining their long-term food security while importing nations in turn become progressively dependent on foreign land resources, such as soil and water, for their food security.

"Virtual land" is a term used to characterize the underlying aspects of international trade in food products that compensate for lack of productive land in the importing country, i.e., the land area and input resources needed to grow the imported foods.[145] Trading in virtual land gives the economically powerful the ability to exploit other countries' land resources to produce their food and biofuel imports; a phenomenon that has further fueled land grabbing. As with other aspects of globalization, the growth in this type of trade means that the balance of power can change radically in a relatively short time. In 1986, China's virtual land import was 4.4 million ha but by 2009 it had risen to 28.9 million ha, mainly from North and South America.[146] Similarly, the European Union requires 43 per cent more agricultural land than is available in the EU itself in order to satisfy its food needs.[147]

Agriculture faces major challenges as a result of climate change and at the same time is also a major source of the greenhouse gases that are causing climate change.

6. Climate change

Agriculture faces major challenges as a result of climate change and at the same time is also a major source of the greenhouses gases that are causing climate change.[148] This brings two complicating factors into predictions about food security: 1) long-term shifts in average climate are gradually moving the optimal areas for specific crops to grow, and 2) an increase in extreme weather events is reducing food security through rainfall or temperature changes[149] and increased plant diseases,[150] livestock diseases,[151] and pest attacks.[152]

Most projections suggest that climate change will reduce food security[153] and increase the number of malnourished people in the future.[154] The Intergovernmental Panel on Climate Change (IPCC) finds more negative impacts than positive ones and projects severe risks to food security, particularly in the tropics where average temperatures are likely to increases 3-4.°C. As a result, food prices will rise steeply and weeds will become more problematic, with rising carbon dioxide levels reducing the effectiveness of some herbicides.[155]

Furthermore, the IPCC concludes: "Under scenarios of high levels of warming, leading to local mean temperature increases of 3-4°C or higher, models based on current agricultural systems suggest large negative impacts on agricultural productivity and substantial risks to global food production and security (medium confidence). Such risks will be greatest for tropical countries, given the larger impacts in these regions, which are beyond projected adaptive capacity, and higher poverty rates compared to temperate regions."

Climate change will likely have varying effects on irrigated yields, with those in South Asia experiencing particularly large declines. One projection suggests that the availability of calories in 2050 could decline relative to 2000 throughout the developing world, increasing child malnutrition by 20 per cent.[156] However, predictions about agriculture and climate are difficult: impacts on food systems will be complex, geographically and temporally variable, and heavily influenced by socio-economic conditions. Most studies focus on availability, whereas related issues of stability of supply, distribution, and access may all be affected by a changing climate.[157] Low-income producers and consumers are likely to suffer the most because of a lack of resources to invest in adaptation and diversification measures to endure price rises.[158]

Box 7.3: Land management impacts on marine communities

The Great Barrier Reef, offshore Queensland Australia, is the world's largest coral reef a UNESCO World Heritage site, and a tourist attraction of huge economic value. Research estimated that the Australia-wide value-added economic contribution generated in the Reef catchment in 2012 was USD 4.4 billion, with just below 69,000 full-time equivalent workers. Some 90 per cent of direct economic activity came from tourism.[184] Yet the reef's living corals have declined almost 50 per cent in the last two decades. Pollution from agriculture is a key factor, including excess nitrogen and phosphorus reaching inshore parts of the reef,[185] suspended sediment from erosion in cattle-growing areas, and herbicides;[186] this along with one of the world's highest deforestation rates due to clearing woodland for cattle pasture, another substantial contributor to sediment pollution.[187] These problems are increasingly found around the world. In the Gulf of Mexico, a "dead zone" resulting from excess agricultural run-off covered 13,080 km^2 in 2014.[188] Around 30 dead zone hotspots have been identified, primarily in Europe and Asia, with the most significant including the Mississippi, Ganges, Mekong, Po, Pearl River, Volga, Rhine, and Danube.[189]

Greenhouse gases are released at almost every stage in the agricultural cycle. According to the 2014 report of the IPCC, the agriculture, forestry, and other land-use sectors (AFOLU) are responsible for just under a quarter of anthropogenic greenhouse gas emissions, largely from deforestation, livestock emissions, and soil and nutrient management (*robust evidence, high agreement*).[159] AFOLU emissions have doubled in the last fifty years and could increase by another 30 per cent by 2050.[160] Crop and livestock production recently surpassed land use change and deforestation in the level of greenhouse gas emissions, now responsible for 11.2 per cent of the total.[161] Climate change impacts of expanding cropland into natural ecosystems differ markedly around the world. For each unit of land cleared, the tropics lose almost twice as much carbon and produce less than half the annual crop yield compared with temperate regions, making it even more important to increase yields on existing cropland rather than clearing new areas.[162] A recent analysis calculated that the livestock sector is responsible for 39 per cent of anthropogenic methane emissions and 65 per cent of anthropogenic nitrous oxide emissions.[163] AFOLU are also carbon sinks which can increase


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their sequestration capacity through conservation, restoration, and sustainable land management practices that increase organic carbon stocks.[164]

ASPECTS OF THE MODERN FOOD SYSTEM

Until now, the focus of efforts to address an impending land crunch has been predominantly on intensification: producing more food per hectare of land by increasing yields, cropping frequencies, and intensifying livestock production through supplementary feed, breeding programmes, and controlled indoor housing.[165] The "green revolution"[166] promoted improved crop varieties supported by chemical fertilizers and a range of pesticides and herbicides; one unplanned outcome being farm unit consolidation and larger industrial monocultures.

Overall, these changes have increased net productivity, lowered food prices, and helped to reduce childhood malnutrition in poor countries since the 1960s.[167] Gains have been greatest in the most commonly grown crops (e.g., cereals, oilseeds, fruits, and vegetables), with increases of an estimated 47 per cent from 1985-2005 due to higher yielding varieties, less crop failure, and multiple annual cropping. For all 174 significant crops assessed, average global crop production increased 28 per cent.[168] Cropland increased only 2.4 per cent over this same period,[169] implying more output per hectare. More profoundly, agriculture became increasingly centralized with a small group of multinational corporations controlling virtually all aspects of food production: from seed, genetic materials, machinery, and agrichemicals to farm production and the transport, processing, and marketing of food. Food transport distances have increased dramatically as have the inputs and energy used in agriculture.

The boost in production and profits has been matched by a steady build-up of side effects and a growing number of "have-nots" who are neglected and continue to suffer malnutrition. The drawbacks of modern farming have been recognized for half a century, since Rachel Carson wrote about the impact of pesticides in the environment,[170] and Susan George identified the unintended side effects of the "green revolution,"[171] including:

- Pollution from agrochemicals such as nitrate and phosphate fertilizers, herbicides, and pesticides
- Irrigation and salinization leading to land and soil degradation
- Crop diseases, invasive pests and diseases, and loss of genetic diversity impacting food security
- Soil and land degradation over a growing area of the planet
- Food miles and the increasing long distance transport of food
- Human health and nutrition with hunger and obesity as converse challenges
- Crop selection and genetically modified crops

1. Pollution from agrochemicals

Modern methods of food production rely on the ability to add enough nutrients, mainly nitrate, phosphate, and potassium (often referred to as NPK) to the soil to boost plant growth and increase yields. All three come with a range of negative environmental impacts, some of which are still not fully understood.

While fertilizers have been responsible for increasing crop yields, the inefficiency in their application leads to major detriment in the wider environment, causing air and water pollution, ecosystem damage, and risks to human health:[173] fertilizers are estimated to be over-used by 30-60 per cent in some situations.[174] Leaching from agricultural areas results in nitrate and phosphate polluting surface and groundwater supplies; excess nutrients promote rapid algal growth and, when the latter die, the loss of oxygen as plant matter decomposes. This process, known as eutrophication, kills fish and other aquatic life. Algal blooms have long been a serious environmental problem in lakes and rivers, and increasingly in offshore marine waters where they create dead zones, i.e., oxygen-depleted water resulting from over-enrichment by nitrogen and phosphorus. Reported cases of coastal dead zones have doubled in each of the last four decades, with over 500 currently known.[175] Nitrous oxide is an increasingly important greenhouse gas, with emissions largely arising from agriculture.[176] Excessive air and water-borne nitrogen has been linked to respiratory ailments, cardiac disease, and several types of cancer.[177] High nitrate levels in water and vegetables[178] can also be a contributory factor[179] in the increased risk of methemoglobinemia (blue baby syndrome) in both temperate and tropical[180] agricultural regions.

Global fertilizer use is still accelerating rapidly and is likely to exceed 200 million tons a year by 2018, some 25 per cent higher than in 2008.[181] Reactive nitrogen added to the biosphere through human activity now exceeds that made available through natural processes.[182] While still relatively low in Africa, nitrogen fertilizer use is generally increasing everywhere with east and southeast Asia together accounting for 60 per cent of total use.[183]

The narrow genetic base in monocultures creates ideal conditions for unwanted species to exploit, exposing agriculture to attacks from a host of invertebrate and fungal pests and diseases, which most farmers control by applying pesticides. Pesticide use is expanding fast, valued at USD 65.3 billion in 2015 and predicted to continue growing annually at about 6 per cent until 2020.

Did you know *that British farmers growing wheat typically treat each crop over its growing cycle with four fungicides, three herbicides, one insecticide, and one chemical to control molluscs. They buy seed that has been precoated with chemicals against insects. They spray the land with weedkiller before planting, and again after. They apply chemical growth regulators that change the balance of plant hormones to control the height and strength of the grain's stem. They spray against aphids and mildew. And then they often spray again just before harvesting with the herbicide glyphosate to desiccate the crop, which saves them the energy costs of mechanical drying.*[172]

Evidence is building that the adverse environmental impacts of pesticides have been underestimated, particularly in the tropics.[190] There is particular concern about a decline in global insect populations (i.e. not just pest species), including catastrophic and economically important impacts on honey bees and wild pollinators.[191] Two recent reports synthesized over a thousand peer-reviewed studies and both concluded that neonicotinoid and other systemic insecticides have serious negative impacts on pollinators and other terrestrial and aquatic invertebrates, amphibians, and birds as well as cause significant damage to ecosystem functioning and services.[192,193] Significant declines in biodiversity[194] are being linked with the increased use of insecticides,[195] fungicides,[196] and herbicides,[197] often acting in combination along with other aspects of modern farming. Species are not even necessarily safe in protected areas because many pesticides drift far from the point of application.[198] These findings help to explain why biodiversity continues to decline in farmed landscapes, even in Europe where habitat loss and poaching pressure have been reduced, and where there has been investment in schemes intended to increase wildlife in production landscapes.[199] Many effects are still largely unstudied, including the impact of pesticide mixtures on human health,[200] but are likely to have high costs in terms of their impacts on both human health and ecosystem services.[201] For instance, the total economic value of pollination worldwide is estimated at USD 165 billion annually;[202] in parts of China, farmers now pollinate plants by hand due to the loss of insect pollinators.[203]

Modern farming methods also rely heavily on herbicides to control weeds. Genetic engineering is increasingly being applied to make crops more tolerant of herbicides. These herbicide-resistant genetically-modified (GM) crops now use 56 per cent of total glyphosate use,[204] and increased herbicide tolerance means that farmers are likely

Box 7.4: Estimates of economic losses due to land degradation[229]

There are wide variations in the estimated global costs of land degradation.[230] Valuation methods vary extensively, from simplistic approaches using land use and land cover data as a proxy for ecosystem services to methods integrating a range of spatial variables which are validated against primary data to derive ecosystem services models and value functions.

Globally, the estimated annual costs of land degradation range between USD 18 billion[231] and 20 trillion.[232] According to the Economics of Land Degradation (ELD) Initiative, the loss of ecosystem services due to land degradation cost between USD 6.3 and 10.6 trillion annually, representing 10-17 per cent of the world's GDP.[233] These costs are distributed unevenly, with negative impacts mostly affecting local communities and the rural poor. The annual global cost of land degradation due to land use change and reduced cropland and rangeland productivity has been estimated at roughly USD 300 billion; most of the costs are borne by those benefiting from ecosystem services, i.e. the farmers.[234]

The ELD Initiative estimated future value of ecosystem services[235] under various different possible futures. [236] Both a future dominated by neoliberal free market economics and one with high levels of protectionism led to dramatic losses of value of ecosystem services, of USD 36.4 and 51.6 trillion per year, respectively. Under conditions of continuing economic growth, but with assumptions about the need for government intervention and effective land policy, there was a relatively small increase in the value of ecosystem services of USD 3.2 trillion per year. Finally, under transformative future policies that overcome limits to conventional GDP growth and focuses on environmental and social wellbeing and sustainability the value increased by USD 39.2 trillion per year. These findings suggest the need to promote adequate policy measures to sustain the socio-economic value of land.[237]

National studies mirror global findings in estimating high costs of degradation. For example in Tanzania and Malawi the annual costs of degradation account for, respectively, USD 2.5 and 0.3 billion, and represent roughly 15 and 10 per cent of their GDP, and in Central Asia the annual costs of degradation across Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan are estimated at USD 6 billion.[238]

to increase the application rate.[205] Herbicides, such as glyphosate and atrazine remain under constant review in terms of their health and environmental effects, with a ban on glyphosate being discussed within the European Union. In developing countries, low literacy, poverty, and the prevailing conditions of pesticide use continue to translate into major risks to farmers, workers, and their families, consumers, and the environment. Since 2006, UN agencies have identified the need for stakeholder action to reduce risks associated with the use of Highly Hazardous Pesticides, including phase outs.[206] Policy makers often assume that current or increased levels of pesticide use are essential to deliver food security. The latest report from the UN Special Rapporteur on the right to food challenges this assumption and highlights the need for a global treaty to govern the use of pesticides.[207]

Harmful side-effects of pesticide use also carry major and often unrecognized economic cost. For example, UN Environment estimates that between 2005 and 2020, the accumulated cost of illness and injury linked to pesticides in small-scale farming in sub-Saharan Africa could reach USD 90 billion if no action is taken to control hazardous pesticides and poor practices.[208]

2. Irrigation and salinization

Salinization involves the accumulation of water-soluble salts in the soil, negatively impacting the health and productivity of the land. Salt-affected soils occur in most countries, although they are more common in the drylands. Salinization inhibits germination and eventually undermines the ability of the soil to support plant growth.

Agricultural losses due to salinization are not well documented but at least 20 per cent of irrigated lands are believed to be salt-affected with some estimates putting the figure much higher;[209] researchers suggest that half of all arable land will be affected by 2050.[210] An estimated 2.7 million ha of the world's rice fields are currently affected by salinization.[213]

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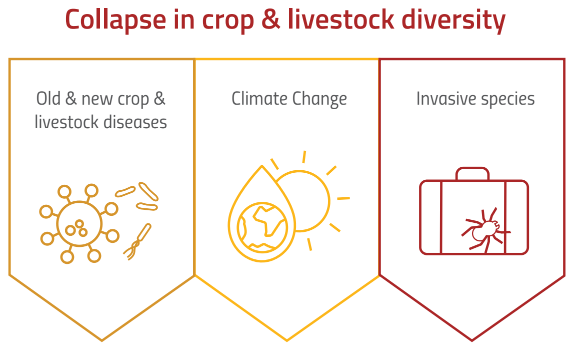

Figure 7.6: The triple effect of diversity loss, emerging crop and livestock diseases and climate change

Beyond its direct impact on agricultural production and food security, salinization also affects groundwater aquifers. When water movement into aquifers is greater than outflows, the water table rises transporting salts to surface soil[214] which undermines future irrigation capacity and compromises domestic drinking water supplies.[215] Salinity is difficult to reverse and often leads to long-term land degradation. As irrigated areas are among the most productive lands, the so-called bread baskets, salinization is undermining global food and water security (see also Chapter 8).

3. Crop diseases, invasive pests and diseases, and loss of genetic diversity

Crop diseases have been a problem for farmers throughout history. Today, additional problems are created by the increased movement of crops around the world, spreading non-native pests and diseases and creating further challenges to increasing food production. At the same time, climate change is adding new stresses to many species and the significant reduction in genetic diversity within crops is reducing their ability to adapt to emerging pressures.

The development of high-yielding crop varieties and the increasing intensification of livestock husbandry based on selected genetic stocks have drastically reduced diversity.

The development of high-yielding crop varieties and the increasing intensification of livestock husbandry based on selected genetic stocks have drastically reduced diversity. It is estimated that about 75 per cent of crop genetic diversity has been lost in the last century due to the abandonment of traditional landraces in favor of uniform crop varieties.[216] While the latter are often more productive, their narrower genetic variation makes adaptation more difficult. A survey found that 97 per cent of the crop varieties, listed in old United States Department of Agriculture catalogues, are now extinct.[217] Similarly in Germany, about 90 per cent of historical crop diversity has been lost, and in southern Italy about 75 per cent of crop varieties have disappeared.[218] Furthermore, many crop wild relatives, important genetic resources for breeding, are also declining or under threat,[219] with some 70 per cent of important crop wild relative species in need of protection.[220] Such losses reduce opportunities for breeders to help crops adapt to a changing climate, to the emergence of new diseases, and to the spread of invasive species that limit production.

Despite the increasing use of pesticides, pests and disease continue to take a heavy toll on crops worldwide. An average of 35 per cent of crop yields are lost to pre-harvest pests[221] while some argue that these losses would be doubled without pesticides.[222] Emerging infectious diseases from fungi are also acknowledged to pose increasing risks to food security[223] as human activities are now intensifying fungal dispersal.[224] Globalization and the long distance transport of foodstuffs have increased the spread of invasive species. Without natural predators, non-native species can sometimes thrive and inflict heavy damages on crops and livestock. In the United States alone, crop and forest losses from invasive insects and pathogens have been estimated at almost USD 40 billion per year.[225] A recent review of 1,300 insect pests and pathogens in 124 countries assessed future risks and found sub-Saharan Africa the most vulnerable to attack, mainly due to the lack of resources to control such events, while the United States and China stood to lose the most in economic terms.[226]

Meanwhile climate change will further exacerbate all these problems, for example, helping pathogens spread to new areas, increasing the number of generations per season, and altering plant defense mechanisms.[227]

4. Land degradation and soil loss

The UNCCD defines land degradation as the reduction or loss of biological or economic productivity in rainfed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as:

- soil erosion caused by wind and/or water;
- deterioration of the physical, chemical, and biological or economic properties of soil; and
- long-term loss of natural vegetation.[228]

It can refer to a temporary or permanent loss of productive capacity, a loss or change in vegetative cover, a loss of soil nutrients or biodiversity, or increased vulnerability to environmental and disaster risks. As discussed in Chapter 4, the extent of areas

Table 7.1: People living on degraded agricultural land (DAL): Adapted from[247]

	share of rural population on DAL in 2000	change from 2000 to 2010 of rural population on DAL	share of rural population on remote DAL	change from 2000 to 2010 of rural population on remote DAL
Developed Countries	**17.9%**	**-2.8%**	**0.8%**	**-1.8%**
Developing Countries	**32.4%**	**+13.3%**	**5.5%**	**+13.8%**
East Asia & Pacific	50.8%	+8.4%	9.0%	+6.8%
Europe & Central Asia	38.5%	+1.0%	3.6%	+4.4%
Latin America & Caribbean	13.0%	+18.4%	1.9%	+17.1%
Middle East & North Africa	22.3%	+14.3%	2.8%	+5.9%
South Asia	26.2%	+17.8%	2.5%	+18.9%
Sub-Saharan Africa	20.6%	+37.8%	5.8%	+39.3%
World	**34.0%**	**12.4%**	**5.0%**	**+13.6%**

Today, consumers in wealthy countries expect to be able to buy fruit, like tomatoes and strawberries, year-round with the apparent paradox of goods flown hundreds of miles often being cheaper than those grown locally.

experiencing persistent declines in land productivity is increasing and thus impacting food production and security. Although global estimates of the costs of land degradation show great variation, they are all high.

Land degradation is driven primarily by socio-economic forces that put people in vulnerable and insecure positions, obliging them to over exploit the land,[239] such as shortening the periods in which they leave fields fallow or eliminating fallows altogether. The privatization of land can confine pastoralists[240] to smaller areas where they have to keep more animals on degrading pastures[241] and must buy fodder or graze their herds in areas that put them into conflict with other land users.[242] These impacts can be observed in Africa, the high Andes,[243] and in Mongolia where demographic changes have led to the concentration of pastoralists near towns and consequent overgrazing in central and western parts of the country.[244] Similar changes are increasing land degradation in northern Vietnam.[245]

Land degradation generally means that less food is produced on the land which has a direct impact on the health and well-being of the resident and nearby communities. The increase in rural populations on degrading agricultural land is seen as a major obstacle to poverty reduction strategies.[246]

5. Food miles

Waste and inefficiencies in our food system increase further when transport is taken into account. Food has been transported since trade routes opened, but in the past long-distance transport was confined to a few high-value foods that could be kept for long periods, such as spices that crossed into Europe along the famous routes through Central Asia.[248] For most people, food was predominantly local and seasonal: fruits and vegetables when they ripened, livestock slaughtered on feast days, and grains and root vegetables carefully stored with surplus processed through bottling or fermentation.[249] With the advent of refrigerated container ships and more recently cheap air freight, the economics of moving food around the world were transformed. Today, consumers in wealthy countries expect to be able to buy fruit, like tomatoes and strawberries, year-round with the apparent paradox of goods flown hundreds of miles often being cheaper than those grown locally.

The concept of "food miles" was developed to describe and quantify this phenomenon, now central to the commercial foundation of agribusiness. In its simplest form, food miles refers to the distance food travels between the producer and the consumer;[250] in the case of processed food, this figure may be the sum of the transport of multiple ingredients.

Food miles have often been used as a surrogate for understanding the carbon footprint of food but this may be too simplistic: research in the United States found that although food is transported considerable distances (on average 1,640 km for delivery and 6,760 km for the life cycle supply chain), 83 per cent of the average US household's food-related CO_2 equivalent emissions come from the production phase. Transport represents only 11 per cent of food's life-cycle greenhouse gas emissions and final delivery from the producer to retail outlets only 4 per cent.[251] The centralized distribution system of major supermarket chains that dominate retail marketing means that the bulk of transportation is actually in the country of sale, even for imported goods. A study by the UK government found food transport reached 30 billion vehicle kilometers in 2002, 82 per cent of which were in the UK. The study calculated that overall greenhouse gas emissions for tomatoes and strawberries from Spain, poultry from Brazil, and lamb from New Zealand were less than the equivalent produced in the UK, even despite the long-distance transport involved. Overall the carbon balance of foods is likely to be influenced largely by a combination of yield, refrigerated storage, and transportation distance.[252] In the UK, research in 2005 found that food and agricultural products accounted for 28 per cent of goods transported by road, imposing estimated external costs of USD 2.94 billion a year.[253]

So while food transport undoubtedly has major impacts, addressing the question of food miles remains complicated. For those concerned with reducing their footprint, it is not just a matter of not buying imported foods but looking at the entire structure of the food industry in the most developed nations.

6. Human health and nutrition

One in nine people in the world are still chronically undernourished and around the same number are considered seriously obese.

One in nine people in the world are still chronically undernourished and around the same number are considered seriously obese. These dietary inadequacies are causing a global health crisis that is threatening to overwhelm medical services, undermine economies, shorten lives, and reduce overall human well-being.

While the percentage of chronically undernourished people in developing countries has fallen from 34 per cent in the mid-1970s to 15 per cent today, some 788 million people remain chronically undernourished, with the total projected to fall to less than 650 million in the next decade, although sub-Saharan Africa will increase its proportion of the total.[254] Regions such as Latin America have made tremendous progress while other parts of the world are still failing to alleviate widespread hunger and malnutrition within their countries. Undernourishment is highest in south Asia (India, Pakistan, and Bangladesh) while progress is slowest in sub-Saharan Africa where one in four people still go hungry.[255]

There are two main types of malnutrition: protein-energy malnutrition which leads to wasting and stunting, and is what is commonly meant when "world hunger" is described; and micronutrient deficiency[256] which can lead to health issues, such as anemia, growth retardation, and cognitive impairment.

Hunger affects the youngest most severely.[257] In 2013, 15 per cent of the world's children under five years old were considered to be malnourished but this figure rises to 22 per cent in sub-Saharan Africa and 32.5 per cent in south Asia:[258] of the 6.9 million deaths of children under the age of five in 2011, one-third were attributable to underlying malnutrition, mainly in these two regions. This does not mean that over two million children literally starved to death although many will have done so. Hunger weakens resistance to disease and infection. Chronic diarrhea often coincides with micronutrient deficiencies so that the lack of access to clean water together with a lack of food creates a vicious cycle of malnutrition and infections leading to premature death.[259]

The principal causes of hunger are poverty (by far the most important globally),[260] the impact of inequitable economic systems, and conflict.[261] The key problem is that almost a billion people do not have enough income to buy adequate amounts of nutritious food, or any land on which to produce or collect food. Rapidly growing populations are also straining food production systems although as mentioned earlier there is still ample food produced globally to feed everyone adequately.

At the same time, the number of people who are overweight is increasing dramatically. In 1995, being overweight was recognized as being a larger problem than malnutrition even in many developing countries and, following a World Health Organization obesity consultation in 1997, its critical role in escalating medical problems and health costs was first recognized.[262] In 2014, over 1.9 billion adults over 18 years old were overweight (39 per cent of the world's population) and 600 million (13 per cent) were considered obese, including 41 million children under the age of five either overweight or obese. Most of the world's population lives in countries where being overweight kills more people than being underweight.[263]

7. Crop selection and genetically modified crops

Crop selection has been a feature of agriculture since prehistoric times. Indeed, the concept of identifying desirable crop traits and enhancing these through selective breeding is one of the most fundamental stepping stones in the evolution of civilization.[264] More recently, sophisticated selection techniques have resulted in high-yielding varieties, which are reliant on heavier applications of agrochemicals, leading to productivity increases in

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important crops but also accompanied by a host of detrimental impacts on human and environmental health. The trade-offs between food production and land degradation are the subject of long, politically charged debates and many policies and laws.[265]

Genetically modified organisms (GMOs) are those whose genetic material has been modified by a variety of engineering techniques performed in the laboratory. One specific type of GMO is a transgenic organism which has been altered by the addition of genetic material from an unrelated organism. The use of GMOs, and particularly transgenic organisms, remains highly contentious; countries and regions have responded in different ways. The European Union insists on all food products containing GMOs to be labeled while in the US,[266] this is not the case as the corporate food industry strenuously opposes labeling. Some critics highlight safety concerns relating to the potential for unintended consequences from genetic alterations while others object on ethical or religious grounds. Some express disquiet about how genetic modification has been used; for example, soybeans and several other crops have been modified to increase their resistance to herbicides, encouraging heavier applications on crops and thus leading to more environmental pollution.

By making crops resistant to pests and immune to the effects of herbicides, the promise of genetic modification is to increase crop productivity and feed the world's growing population while using less pesticide. However, extensive studies, including research by the GMO industry itself, reveal that genetic modification in the United States and Canada has not accelerated increases in crop yields (when measured against Western Europe) or led to an overall reduction in the use of chemical pesticides.[267] A recent report found that "there was little evidence" that the introduction of genetically modified crops in the United States had led to yield gains beyond those seen through the use of conventional crops.[268]

Box 7.5: Traditional breeding for drought tolerance – Years ahead of GM efforts

Genetic engineering lags behind conventional breeding in efforts to create drought-resistant maize. The need for more resilient crops is especially acute in Africa, where drought can reduce maize (corn) yields by up to 25 per cent. The Drought Tolerant Maize for Africa project, which launched in 2006 with USD 33 million, has developed 153 new varieties to improve yields in 13 countries. In field trials, these varieties match or exceed the yields from commercial seeds under good rainfall conditions, and yield up to 30 per cent more under drought conditions. The higher yields from drought-tolerant maize could help to reduce the number of people living in poverty in the 13 countries by up to 9 per cent.[269] In Zimbabwe alone, that effect would reach more than half a million people. Since its launch in 2010, the project has developed 21 conventionally bred varieties in field tests which yielded up to 1 ton per hectare more in nitrogen-poor soils than did commercially available varieties. The project's researchers say that they are at least 10 years from developing a comparable GM variety.[270]

CONCLUSION: TRANSFORMING OUR FOOD SYSTEMS

Something is very wrong with the way we produce, market, and consume our food. A billion people do not have enough to eat while another billion suffer the consequences of being overweight.

Our current agriculture practices use enormous amounts of scarce water and energy supplies, and contribute to the very climate change that threatens the entire food system.

At least one-third of our food is wasted and every year, irreplaceable agricultural land is degraded and lost through mismanagement. Our dwindling natural ecosystems are being destroyed for agriculture, with a food industry still acting as if land resources were infinite. The pollution from agriculture is reaching critical levels in many places yet most research focuses on ways of using more agrochemicals rather than on ways of using less. Our current agriculture practices use enormous amounts of scarce water and energy supplies, and contribute to the very climate change that threatens the entire food system.

Most farmers are deeply committed to the long-term health and productivity of their land. The fact that many are caught in an unsustainable management spiral is a cause of deep distress. Farmers are trapped between the demands of a food system that is squeezing them financially, a public demanding cheap food, and multiple competing land uses. It is no wonder that farmers are among the highest groups at suicide risk in many countries.[271] A fundamental transformation of our entire food system is well overdue. Such a transition towards net positive food systems depends on the development and implementation of a proactive agenda.[272]

A ten point plan for land management and human security based on rights, rewards, and responsibilities

In the future, there will be more people to feed. Food security is under threat and there is no single solution to this challenge; instead the world will need to make a coordinated effort to address shortages, degradation, inequalities, and waste. Ten key steps will be essential; these are listed below and then outlined in more detail. Some of these are already well underway and need to be further supported by national policies and consumer decisions; others require a more fundamental rethinking of the way we approach the entire food system, from production and distribution to consumption. So far, the response has been narrowly focused on intensification, which has boosted food production but has also produced a wide range of side effects including pollution, salinization and land degradation, pests and diseases, invasive species, and the loss of genetic variability and evolutionary potential.

These ten steps would move us closer towards a multifunctional approach to food production which emphasizes human health, ecosystem services, resource efficiency, and above all sustainability for future generations.

1. Close the gap between actual and potential yield in all environments
2. Use land, water, nutrients, and pesticides more efficiently
3. Reduce offsite impacts of food and non-food production
4. Stop expanding the agricultural frontier
5. Shift to more plant-based and whole food diets
6. Raise awareness about health, sustainability, and responsibility
7. Reward sustainable land management practices
8. Reduce food waste and post-harvest losses
9. Improve land tenure security, access to nutritional food, and gender equity
10. Implement integrated landscape management approaches

1. Close the gap between actual and potential yield in all environments

Having sufficient food to feed the world's population until the end of the 21st century is often based on the assumption that it is possible to keep increasing crop yields. However, many experts remain deeply skeptical, and believe that many of the predictions for yield increases are overly optimistic.[273]

Even if yields were brought up to only 75 per cent of their potential, global production would increase by 1.1 billion tons.

The yield gap is the difference between actual crop yields and potential yields at any location given current agricultural practices and technologies. It is much easier to increase output for crops with large yield gaps than it is to boost production on already high-yielding farms. Yet much of the agricultural research and extension still focuses on the latter. Shifting attention to closing the yield gaps, without excessive environmental and resource costs, would provide more immediate and cost-effective gains in food production in much of the developing world. Bringing yields to within 95 per cent of their potential for 16 important food and feed crops would result in an additional 2.3 billion tons or a 58 per cent increase. Even if yields were brought up to only 75 per cent of their potential, global production would increase by 1.1 billion tons.[274]

Global yield variability in crops is determined primarily by nutrient levels, water availability, and climate. Large production increases, of 45 to 70 per cent for most crops, are possible mainly through increased access to nutrients, and in some cases to water coupled with reduced nutrient imbalances and inefficiencies. Research suggests that there are large opportunities to reduce nutrient overuse while still allowing for an approximately 30 per cent increase in the production of major cereals (e.g., maize, wheat, and rice).[275]

The responsibility for closing yield gaps rests less with scientists and researchers, and more with extension workers, governments, farming organizations, the food industry, and civil society as well as their capacity to share expertise, make resources available, and provide market infrastructure; and with farmers and producers themselves.

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2. Use land, water, nutrients, and pesticides more efficiently

Food insecurity can be reduced simply by eliminating much of the loss and waste in the system: e.g., through capacity building among food producers, commitments to better stewardship, and the introduction of improved technologies. These efforts of course need to be supported by policy incentives and a reduction in perverse subsidies that encourage wasteful water and agrochemical use.

Many farmers currently use pesticides very inefficiently[277] without understanding their side effects[278] and thus becoming "locked in" to an increasing cycle of use[279] of what may sometimes include banned products.[280] Furthermore, much of the equipment used to apply pesticides remains relatively crude, resulting in both drift of very small droplets and wastage through release of large droplets.[281] Improved technologies and smart application procedures can dramatically reduce pesticide volumes[282] and thus offsite impacts and toxic loads. Improved technical options exist but uptake often remains low;[283] legal loopholes in many countries foster misuse.[284] Improving efficiency will also require more investment in research. In many countries public funding for research has been reduced on the basis that pesticide companies should pay but understandably have little incentive to invest in systems that would reduce their sales.

A suite of well-known management techniques exists to conserve water, such as conservation agriculture, the use of manures and compost, vegetative strips to control run-off, agroforestry, water harvesting, gulley rehabilitation, and terracing.

Similar options exist to reduce fertilizer inputs and water use, most notably through integrated national or regional plans.[285] Soil and crop nutrient testing, improved timing of application (identifying suitable weather conditions), slow-release and controlled release fertilizers, use of urease and nitrification inhibitors to decrease nitrogen losses, and placement rather than broadcast application, can all reduce fertilizer waste.[286] A suite of well-known management techniques exists to conserve water, such as conservation agriculture, the use of manures and compost, vegetative strips to control run-off, agroforestry, water harvesting, gulley rehabilitation, and terracing.[287]

The concept of "sustainable intensification" is gaining traction, defined as any effort to "intensify" food production that is matched by a concerted focus on making it "sustainable," i.e., minimizing pressures on the land and the environment. Integrated Pest Management approaches are now being used on millions of farms: research demonstrates that higher yields can be achieved with reductions in pesticide use,[288] more intra-specific crop diversity to manage pests,[289] and suggests that efficient agriculture does not require the adoption of large-scale monocultures.[290] Small-scale, labor-intensive, low-input farming systems frequently lead to higher yields than conventional systems.[291] Extension approaches such as Farmer Field Schools, promoting education, co-learning, and experiential learning can help to reduce the wasteful and unnecessary use of pesticides.[292] Yet there is much less investment in research into low-input systems, and this approach continues to remain undervalued.

Box 7.6: Closing the yield gap in Brazil

In the case of Brazil, a country rich in terrestrial carbon and biodiversity, agricultural production is forecast to increase significantly over the next 40 years. A recent study produced the first estimate of the carrying capacity of Brazil's 115 million hectares of cultivated pasturelands, where researchers investigated if the more sustainable use of these existing production lands could meet the expected increase in demand for meat, crops, wood, and biofuels. They found that current productivity is at 32-34 per cent of its potential and that sustainable intensification to bring productivity to 49-52 per cent would provide an adequate supply of these goods until at least 2040, without further land or ecosystem degradation and with significant carbon sequestration benefits.[276]

3. Reduce offsite impacts of food and non-food production

The side effects of the current food system threaten to undermine the very processes it seeks to maintain by emitting greenhouse gases and degrading the biological and economic potential of the land. Efforts to alleviate the offsite impacts of food production need to focus on management practices that ensure the more efficient delivery of agrochemicals to reduce leakage into the wider landscape as well as the development and application of safer and effective alternatives. Efforts to close the yield gap (Step 1) will only produce a net benefit if offsite impacts are reduced at the same time, i.e., sustainable intensification.

An analysis of 85 projects in 24 countries calculated that half of all pesticides used are unnecessary.[293] Farmers often rely heavily on advice from agrochemical companies or their agents.[294] In 2014, the US Environmental Protection Agency concluded

Box 7.7: Precision agriculture

Agriculture has been one of the last industries to embrace an information-driven, real-time business approach. Precision agriculture uses sophisticated monitoring technology to assess variables such as soil and weather conditions, coupled with modeling tools, to help growers adjust farm operations in response to intra-field variability.[296] The incorporation of objective real-time advice across the crop cycle helps growers optimize choices on what, when, and where to plant, and what to apply to the plant and soil. It helps to increase production efficiency while reducing on-site degradation of soil and offsite environmental impacts. Precision agriculture relies on an ability to capture, interpret, and assess the economic and environmental benefits of particular management actions.[297]

that applications of neonicotinoid seed dressings to soybean provide "limited to no benefit" yet they were widely used at a cost to farmers of USD 176 million per year.[295] Major efforts at reducing agrochemical use and leakage could be made using current technology, including a detailed matching of crop needs and conditions as in precision agriculture. Clear, unbiased advice and support to farmers is a critical step in this process.

In the short term, efforts at reducing offsite pollution should focus on where the greatest gains can be made, or where the impacts are most severe. China, India, and the United States collectively account for 65 per cent of excess nitrogen and phosphorus usage globally; focusing efforts on improved fertilizer efficiency to a small set of crops and countries could potentially reduce global nitrogen and phosphorus pollution with further efficiency gains achieved by modifying the timing, placement, and type of fertilizer used.[298]

One critical offsite impact is greenhouse gas emissions from agriculture. In some cases, these may be hard to reduce without major changes to production systems, such as reducing emissions from ruminant animals. In other food production systems, minor changes in practices can make a big difference, such as using different crop varieties or species, planting at different times of the year, and making use of accurate climate forecasting.[299] Species selection along with water, soil, and stubble management can reduce emissions from rice production.[300] Regenerative forms of agriculture, which make use of natural processes to help build soils, retain water, sequester carbon, and increase biodiversity, are receiving increasing attention.

Table 7.2: Elements of precision agriculture

Categories	Advice Offered	Description
Crops	Variety selection	Seed variety selection
	Best planting times	Right time and conditions for planting
	Variable seeding rate	Seeding based on intra-field variability
Fertilizer use	Variable fertilizer rate	Nutrient application based on intra-field variability
	Field maps	Field maps to assist precision application
	Variable application rate	Chemical application based on intra field variability
	Sustainability advice	Steps towards sustainable resource optimization
Pest and disease management	Disease diagnostics	Predictive or diagnostic assessment
	Scale of pest problems	Predictive and diagnostic models
	Protocol advice	Scalability for image-based diagnostics; model driven algorithms
Crop health	NDVI/EVI indices	Satellite/drone imagery using Normalized Difference Vegetation Index and Enhanced Vegetation Index to assess field conditions
	Weather/field alerts	Predictive models based on weather-driven agronomic planning
	Monitoring soil nutrients	Algorithm-driven field nutrient mapping
	Biomass mapping	Field monitoring of organic matter

Box 7.8: Organic agriculture and integrated production systems

Various types of agriculture can have a place in feeding the world depending on the availability of land, the degree of self-reliance of agricultural systems in terms of critical inputs to value chains, such as nutrients and other resources, the scale of food production, and the desired and feasible trade in agricultural goods.[301] Organically grown food, beverages, supplements, cosmetics, and other goods are a rapidly growing market in the developed countries and among the emerging middle classes in the developing world. The perceived human health (nutritional) and environmental benefits are the primary drivers of this market growth. Over a quarter of the world's organic agricultural land and more than 1.9 million, or 86 per cent, of the world's organic producers, are in developing countries and emerging markets, notably India (650,000), Uganda (189,610), and Mexico (169,703).[302] Organic agriculture is defined and verified by global and national standards.

Organic agriculture addresses many of the drivers of land degradation and their offsite impacts by eliminating chemical fertilizers and most pesticides, helping to build soil organic matter, and applying water conservation methods. There are already over 43 million hectares of organic production worldwide, with a further 35 million hectares of natural or semi-natural areas used for the collection of "wild" organically certified products, such as honey and herbs.[303] In most cases at large-scales, organic systems produce lower yields than conventional systems, however they generally protect associated ecosystem services, and demand has risen steadily: in 2013, global sales were worth USD 72 billion and are predicted to double by 2018.[304] There is strong evidence that organic agriculture supports more biodiversity.[305] Organic farming focuses on increasing soil organic matter, maintaining on-farm biodiversity, and using less energy,[306] however, in some cases organic farming may cause nutrient mining of the soil and in the long run may diminish soil organic matter.[307] A recent meta-analysis shows that under some circumstances organic agriculture comes close to matching the yields of conventional agriculture while in other cases it does not.[308,309] Productivity in organic agriculture is being further boosted by introducing greater crop diversity under integrated pest management and thus substituting companion plants for pesticides.[310] The role of organic agriculture is currently undervalued in addressing food security issues and offers significant opportunities for further development.

4. Stop expanding the agricultural frontier

Further agricultural expansion into natural ecosystems, primarily through deforestation and other land use changes, such as converting pasture to crops, carries unacceptably high costs, in terms of biodiversity and ecosystem services lost, and often for very modest returns in terms of the food produced.[311] Where expansion is absolutely necessary, this should occur in areas already degraded and where there is little to be lost or recovered,[312] or abandoned land where ecosystem services can be regained by converting to farmland. Even here, the selection of sites needs to be carried out with care. For instance, many *Imperata grasslands in Asia developed as a result of unsustainable swidden practices and appear to be degraded but nevertheless continue to support subsistence agriculture.*[313] Planning and managing land use change requires strong leadership and institutions but can also be influenced by business and consumers; for example, several certification schemes stipulate that the products they cover, such as palm oil and soybean, do not come from plantations established on newly-cleared forests (see Step 6).

5. Shift to more plant-based and whole food diets

Changing diets, especially in the richer countries, could have major positive impacts on both personal health and the condition of the land. Virtually every scenario of future food availability shows that reducing meat consumption, especially beef, is the quickest and most effective way to increase food security and reduce carbon emissions and offsite impacts.[314] Even a slight reduction, to the level recommended by health officials,[315] would incur major savings in land and its resources. For example, reallocating the land currently used for cattle feed in the United States to producing poultry feed would meet the caloric and protein demands of an additional 120-140 million people.[316]

Dietary reforms need to address the time bomb of chronic obesity and its impacts on well-being, lifespan, health services, and economies.[317] Bad diets, many of them implicitly promoted by major retailers,[318] have already undermined the health of a billion people. Public health campaigns have been struggling to convince a generation hooked on fast foods and a high-protein, high-fat diet. Health

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education based on positive encouragement, rather than "fat shaming,"[319] more exercise,[320] additional taxes on unhealthy foods (in the region of at least 20 per cent),[321] and where necessary legislative controls, are all needed. The emergence of sugar taxes, a soda tax in Mexico,[322] and similar initiatives show that many governments increasingly recognize the scale of the problem.

One way to highlight the stark differences is to evaluate agricultural productivity in terms of people fed per hectare rather than by tons per hectare. Based on the current mix of crop uses, food production exclusively for direct human consumption could potentially increase available calories by up to 70 per cent, enough to feed four billion people, and even slight changes in crop allocations for animal feed and biofuels would significantly increase global food availability.[323] A switch to less processed foods and less meat will ultimately lead to more sustainable practices in food production.

6. Raise awareness about health, sustainability, and responsibility

Experience shows that many people are prepared to make healthy and ethical choices about food when they are given accurate and timely information. Both mandatory and voluntary schemes have a role to play. Government-led, obligatory labeling schemes that provide information about nutritional information, calorific value, dietary advice, and health risks are able to persuade many consumers, as has been shown for example by controls on cigarette advertising.

At the same time, the growth of voluntary product certification schemes supports consumers prepared to choose and invest in products that minimize environmental degradation and their carbon footprint. The rapid growth of fair trade and environmental certification schemes over the last two decades provides the basis for more sustainable production, because standards of good management and systems are in place to ensure that scheme participants keep to their commitments. Table 7.3 outlines some of the more prominent schemes.

7. Reward sustainable land management practices

Farming is the biggest use of land on the planet and farmland is in short supply. In the future, farmland will need to be managed much more consciously for the delivery of a full suite of ecosystem services not just food, fiber, and fuel.[335] Agriculture needs to shift from being a source of climate change to a sink for carbon. Many of the steps towards lower greenhouse gas emissions are the same as those already identified: less nitrogen-based fertilizers, lower fossil fuel energy use, better management of waste, increased soil organic matter, ecological restoration, and improvements in irrigation.[336] Agricultural soils need to be conserved, both for the sake of productivity and to avoid downstream impacts. Pollinators, which are facing extreme threats in some areas, require dedicated conservation approaches.[337] In some cases, this more holistic form of management has been in place for decades or centuries; in others it will require a fundamental shift in attitudes.

It will also mean a shift in the way that farmers do business. If farms are expected to provide multiple benefits, they need to be paid for these; greater diversification may mean, for example, that a greater proportion of agricultural income comes from innovative funding sources, such as Payment for Ecosystem Service (PES) schemes.

Engineering a shift towards rewards for land managers based on multiple functions and services will require actions at every level: subsidies and incentives at the local, national, and sometimes global scale; equitable stakeholder platforms linking business, local authorities, extension agents and NGOs with ecosystem providers, such as land managers, individual farmers, or cooperatives; valuation systems to ensure fair prices and financial mechanisms for collection and disbursement of financial and other forms of compensation. While there is a growing body of experience, much more still remains to be learned.

8. Reduce food waste and post-harvest losses

Given that one-third of food produced never reaches the consumers' stomachs, reducing waste would appear at first sight to be an easy win in terms of food and nutritional security. But in practice this will not be easy as a culture of waste has been woven into the fabric of our food systems through purchasing and trade policies, food regulations, and the economics of distribution and retail. It will entail changing the rules on sell-by dates and consumer attitudes towards misshapen fruit and vegetables, a major pubic re-education campaign about our culture of waste and what constitutes desirable or acceptable food, and ultimately changes in the structure of a food industry that is based on the large-scale and constant movement of food products.

Box 7.9: Payment for Ecosystem Services (PES)

It is theoretically possible to collect user fees from people and companies benefiting from ecosystem services to help pay for potential benefits foregone by the people managing the ecosystems producing these services. PES schemes (also called Payment for Environmental Services) can be an important way of supporting farmers and land managers providing these services;[338] for example, by protecting forest to maintain water quality or by reducing stocking levels in hilly country to encourage vegetation growth to reduce flooding. About 80 per cent of Quito's 1.5 million population receive drinking water from two protected areas: Antisana (120,000 ha) and Cayambe-Coca Ecological Reserve (403,103 ha). The government is working with a local NGO and farming communities to protect the watersheds, including stricter enforcement of protection to the upper watersheds and measures to improve or protect hydrological functions and waterholes, prevent erosion, and stabilize banks and slopes.[339] PES schemes suitable for farmers currently focus on carbon sequestration, forest conservation, watershed protection, and disaster risk reduction; payments can be either in cash or in kind, such as equipment, beehives, etc.[340] The value of ecosystem services from agriculture are huge; the challenge lies in finding politically and socially acceptable ways of ensuring that the farmers stewarding these values get adequate compensation.[341]

However, it is very easy to make a start. Many technical, policy, and lifestyle options exist for cutting waste, including facilitating food redistribution and donations, using evaporative coolers in places where refrigeration is unavailable, introducing hermetically sealed plastic storage

Figure 7.7: Food losses along the food chain: Redrawn from[345]

	PRODUCTION	POST PRODUCTION	PROCESSING	DISTRIBUTION	CONSUMPTION
VALUE CHAIN STAGES	Preharvest Harvest Breeding	Handling Storage Transport	Canning Packaging Transformation	Retail Transport	Preparation Table
CAUSES OF LOSS	Damage/spillage Left behind in fields Pests/diseases Weather Wrong imputs	Degradation Pests Premature animal death Spillage	Degradation Discard Spillage	Degradation Discard Excess supply Spillage Spoilage	Discard Excess preparation Spoilage

Table 7.3: Voluntary certification schemes

Voluntary certification scheme	Remit and background
Bonsucro **Better Sugarcane Initiative**	Fostering the sustainability of the sugarcane sector, Bonsucro has almost 200 members from 27 countries.[324]
Climate, Community and Biodiversity Alliance	A multi-organizational initiative promoting land management activities that credibly mitigate climate change including REDD+ projects.[325]
Fair Trade International	Sets global standards for trade that gives farmers a decent livelihood with many individual standards for producer and trader groups and for individual products.[326]
Forest Stewardship Council	One of several forest certification schemes which imposes controls on the clearing of natural woodlands.[327]
Global Roundtable for Sustainable Beef	Promotes responsible beef production throughout the supply chain.[328]
Initiative for Responsible Mining Assurance	Developing a certification scheme for mining operations.[329]
International Federation of Organic Agriculture Movements	International body setting overall standards for organic agriculture with national standards that need to meet those of IFOAM.[330]
ProTerra	A Dutch-based group certifying all aspects of the food chain.[331]
Roundtable on Responsible Soy	Reducing environmental impacts of soybean: there are currently 181 RTRS members and 1.3 million tons of certified soybean were sold in 2014.[332]
Roundtable on Sustainable Palm Oil	Reducing the environmental and social impacts of oil palm production, RSPO has over 2,000 members and over 3 million hectares certified.[333]
Sustainable Agriculture Network	A coalition of non-profit organizations promoting environmental and social sustainability of agriculture through development of best practice standards, certification, and training.[334]

bags or plastic crates for crops, using smaller metal silos, reducing confusion about food date labels, conducting consumer awareness campaigns, and reducing portion sizes at restaurants and cafeterias. Waste reduction targets need to be set by governments; if the current rate of food loss and waste could be cut in half by the year 2050, for instance, it would produce roughly 22 per cent of the gap between the food produced today and projected demand by the middle of the century.[342]

In developing countries, food waste and losses occur mainly at early stages of the food value chain and can be traced back to financial, managerial, and technical constraints in harvesting techniques as well as distribution, storage, and cooling facilities. Cooperation among farmers could reduce the risk of overproduction by allowing surplus crops from one farm to solve a shortage of crops on another.[343] Poor storage facilities and lack of infrastructure cause post-harvest food losses in the tropics; overcoming this challenge will require improved infrastructure for roads, energy, and markets, and ultimately storage and cold chain facilities.[344] The lack of processing facilities also results in food losses due to the seasonality of production and the cost of investing in processing facilities that will not be used year-round.

9. Improve land tenure security and gender equity

Most of the steps above apply equally to the whole food system and indeed the planet. But in the context of food security, it is the poorest that suffer the most, including rural dwellers without access to land and urban dwellers too poor to buy sufficient food to feed their families. The recognition that we have a massive problem of obesity must not obscure the fact that almost as many people are underweight due to lack of sufficient nutrition and, under current projections, this number is likely to increase in the future. A food system that explicitly fails to address the needs of the poor, landless, and powerless will fail to provide food security,[346] and recent trends have tended to increase their vulnerability.

A critical element of success is the recognition of women's rights to secure land tenure, separate from male members of the family. Such rights need to be set out in law in countries where this has not happened, and publicized, explained, and implemented in places where legal changes have not made much difference to everyday practices. Gender issues extend beyond just ownership and influence the type of agriculture practiced. In countries where agricultural labor is mainly left to women, greater equity in working conditions must also be encouraged, both to increase overall well-being and to ensure maximum efficiency.

Food justice is thus about far more than just the volume of food produced. Strategies that aim to develop resilient food systems need to look beyond traditional farming issues to consider, for example, issues of gender equity and social justice that shape access to land and natural resources; adopting integrated agro-ecological approaches to produce more food with reduced environmental impacts; supporting more regionally organized food systems; and embedding access to healthy and culturally-relevant foods within production policies.[347]

Land redistribution from wealthy owners of large farms to land-poor farmers, tenants, or farm workers can foster economic growth, poverty reduction, and gender equity if managed well and supported by strong policies and capacity development. For example, community-based land reform in Malawi led to improvements in landholdings, land tenure security, crop production, and productivity as well as increased incomes and food security.[348]

Land reforms aimed at distributing land to the poor need to steer a delicate course that redistributes land without causing political tension or undermining the position of existing smallholders. This must, for example, include elements to enhance the purchasing power of the poor, remove incentives for land consolidation, and provide sufficient subsidies and extension services.[349]

10. Implement integrated landscape management approaches

To some extent, Step 10 is the summation of the previous nine. Increasing pressure on the agricultural land base, widespread land degradation and desertification, rising pollution, climate change, and growing human populations means that the world needs to move away from a narrow focus on food production and see farmland as part of a multifunctional landscape that supplies food but is also responsible for a wide range of supporting, regulating, and cultural services.

Managing the increasing competition for and trade in land-based goods and services as well as different stakeholder interests requires land use planning to ensure efficient land allocation that promotes sustainable land use options and helps balance competing uses. Land use planning is not a simple land valuation, which can be very attractive for urban developers and detrimental for agriculture; neither is it a land capability classification. Comprehensive land use planning covers all potential uses of land including areas suitable for agriculture, forestry, urban expansion, wildlife, grazing lands, and recreational areas. By modifying spatial landscape structure and allocating land use activities to optimal places in the landscape, it is possible to enhance the production of multiple services and the resilience of the land system.[350] In this way the designed systems would better accommodate local interests and ecosystem service demand, be sustainable from both local and landscape perspectives, and implemented within the local socio-economic and land governance context.[351] Another major aspect of these systemic changes includes the psychological and social aspects of changing practices that have sometimes been accepted for centuries, requiring collaborative approaches with a wide range of stakeholders,[352] including industry.[353]

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