2. Greening Food Supply in Advanced Economies

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"One of the most fateful errors of our age is the belief that "the problem of production" has been solved."

— *Ernst F. Schumacher*

For centuries, agriculture was dominated by family-owned farms raising diversified crops and livestock. Today, food and agriculture, also known as the agri-food sector, is a circa US$6 trillion industry responsible for feeding the planet and hiring well over 40 percent of it (McKinsey, 2015; FAO, 2018; Euler Hermes, 2019). Following sectoral policies aimed at boosting production volumes and profits, and a hasty financialization all along the "food chain" (Clapp, 2016; Schmidt, 2016), the agri-food sector in advanced and large emerging market economies has become heavily industrialized and reliant on large-scale monoculture, a narrowing down of crops, heavy use of fossil fuels and machinery, synthetic chemical applications, genetic modification, and deforestation to produce growing amounts of meat, dairy, and eggs, as well as fiber, timber, and biofuels (Willet et al, 2019) (Figure 1). At sea, high-tech techniques like sonar and equipment like super trawlers with mechanized nets make it possible to exploit deeper waters at farther-flung locations and capture fish faster than they can reproduce.

In low-income countries, poor farming and fishing practices, over-reliance on non-food crops, and climatic extremes have put communities and biodiversity at great risk. Land clearing

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leads to the destruction of native forests, soil erosion, and poor harvests. Local fish stocks are regularly ransacked by global commercial fishing vessels. Low sectoral productivity, because of both rising temperatures and abnormal weather events, constrains both income and food security, pushing many farmers and fishers toward poaching or charcoal production to make ends meet.[1]

The Most Polluting Sector in the World

As a result of all these transformations, the agri-food sector now creates a quarter to a third of human-produced greenhouse gas emissions—a share expected to increase to a half of all such emissions by 2050—while another 8 percent of emissions results from non-food agriculture and deforestation, according to the IPCC's 2019 Special Report on Climate Change and Land and the EAT-Lancet Commission (Figure 2). Thus, the agri-food industry is currently responsible for up to 37 percent of total net anthropogenic GHG emissions, and is, thus, de facto the number one enemy in the fight of climate change (IPCC, 2019). Cows, sheep and goats, a major source of meat and dairy, have an outsized impact because they release methane, one of the most potent greenhouse gases. There are about 1.5 billion cows in the world, a population second only to humans among large mammals. They can be raised anywhere: from the equator, to the Artic, on prairies, in deserts and on mountains. Livestock account for around 15 percent of the world's greenhouse gases each year, according to conservative estimates by the UN's Food and Agriculture Organization.[2] That roughly equals the emissions from all the world's cars, trucks, airplanes, and ships. Critically, emissions of methane (CH_4) as well as nitrous oxide (N_2O) from farmed ruminants are believed to be more key to solving the climate problem than direct CO_2 emissions. While in fact methane, which is the most emitted gas by cattle and is released through belching, does not linger as long in the atmosphere as carbon dioxide, it is initially far more devastating to the climate because of how effectively it absorbs heat. In the first two decades after its release, methane is 84 times more potent than carbon dioxide. So it turns out that if we halted all fossil fuel burning today, we would not see a signal in global temperatures for decades because of the delay in temperature increase as the climate catches up with all the carbon that's in the atmosphere.[3] After maybe 40 more years, the climate would stabilize at a temperature higher than what was normal for previous generations. However, if we eliminated all methane and nitrous oxide emissions today from livestock, we would dramatically increase our chances to stabilize the 1.5C° increase in temperature by 2050 as recommended by the IPCC because these greenhouse gases have a considerably stronger heat trapping potential over shorter horizons than carbon dioxide per se (IPCC, 2019; Rockström, 2016). Fires set in the Amazon rainforests and central Africa to make room for pasture illustrate the dramatic trade-offs between cattle ranching, monocultures (soya, palm tree), biological diversity, and the planet's eroding ability to absorb human-emitted carbon dioxide (Figure 3).

Beyond its direct impact on climate change, the agri-food sector uses a lot of the planet's resources, including about half the world's ice- and desert-free land and three-quarters of its fresh water (Figure 4). Farming depletes these resources because of routine discharges of pollutants, like antibiotics, pesticides, synthetic fertilizers, and manure; discharges of genetically modified organisms and sediment to surface and groundwater; and loss of topsoil as well as salinization and waterlogging of irrigated land. Current farming methods have been found to degrade soil more than 100 times faster than new soil is formed. Climate change exacerbates land degradation, particularly in low-lying coastal areas, river deltas, drylands and in permafrost areas (IPCC, 2019). Agriculture is also the prime cause of earth's current mass extinction, according to the UN's Intergovernmental Science-Policy Platform on Biodiversity and

Ecosystem Services (2019). Overall, half of current global food production vastly exceeds the capacity of the planet to sustain it (Gerten et al., 2020).

Cloudy Skies

Several global trends and natural constraints are expected to worsen this picture considerably in coming decades, influencing the overall sustainability of global food and agricultural systems and, thus, casting a dark shadow on global food security (FAO, 2018, 2019).

First, the world's population is expected to grow to almost 10 billion by 2050, boosting agricultural demand—in a scenario of modest economic growth—by some 50 percent compared to 2013 (UN, 2019).[4] As the global population swells and more people demand animal products, achieving targets to limit climate change will become harder because income growth in low- and middle-income countries is expected to hasten a dietary transition towards higher consumption of animal protein, relative to plant-based protein, requiring commensurate shifts in output and adding pressure on natural resources (Bajzelji et al, 2014; Willett et al, 2019). The expected increase of population and income levels between 2010 and 2050 could increase by 50-90 percent the environmental effects of the global food system (Springman and al, 2018). And without action, by 2030 the livestock sector alone could account for 37 percent of the emissions allowable to keep warming under the 2°C target, and 49 percent if the temperature goal is 1.5°C (Harwatt, 2018).

Second, biodiversity is shrinking at an exponential rate, posing major risks to the future of global food and agriculture: crop and livestock total diversity has narrowed over the past 50 years because of the expansion of industrial monoculture and global seed patenting, and consequently the composition of the diet at the global level has become more uniform at the expense of regionally important crops, as shown by a meta-study across 150 countries (Khouri et al, 2016).[5] While 6,000 plant species are cultivated for food, just nine of them account for two-thirds of all crop production. When it comes to livestock, around a quarter of breeds are at risk of extinction: just a handful provide the vast majority of meat, milk and eggs; and more than half of fish stocks are at risk of extinction (IPBES, 2019) (Figure 5). This lack of dietary diversity is an additional threat to food security and human health. Wild food species are also rapidly disappearing, with just under a quarter of known wild food species are still in existence. In addition, species that contribute to the food ecosystem, such as pollinators, soil organisms and natural enemies of pests, are under sever threat. Examples include bees, butterflies, bats and birds (FAO, 2019; IPBES, 2019).

Finally, as the value added and employment generated by agriculture continue to decline at different speeds, the needed acceleration in productivity growth to ensure that supply keeps up with demand is in turn hampered by global warming—via changes in average temperatures, rainfall, and climate extremes (e.g., heat waves) and rise in seal levels (Figure 6). Future climate change will likely negatively affect crop production in low latitude countries, while effects in northern latitudes may be positive or negative (Figure 7). More favorable effects on yield tend to depend to a large extent on realization of the potentially beneficial effects of carbon dioxide on crop growth and increase of efficiency in water use. Decrease in potential yields is likely to be caused by shortening of the growing period, decrease in water availability and poor vernalization (IPCC, 2019). Beyond temperature and regional climate events, agricultural productivity is also going to be affected by the degradation of natural resources, the loss of biological diversity, and the spread of transboundary pests and diseases of plants and animals, some of which are leading to the spread of zoonotic diseases such as avian and swine flu, while others are becoming resistant to antimicrobials with potentially pandemic consequences (O'Neill et al, 2016).[6]

Meeting increased demands on agriculture with current farming practices is expected to give rise to larger greenhouse gas emissions, fast-track climate change, intensify competition for natural resources, and exacerbate deforestation and land degradation. It follows that greening agri-food sectors and demand-managing food is scientifically recognized as a necessary condition for meeting both the 2030 UN Agenda for Sustainable Development and the environmental pledge behind the UN Paris Climate Agreement (Rockström et al, 2017; IPCC, 2019).

Production 1.5°C Targets

Making food systems sustainable for a growing global population is technologically possible but involves a fundamental reconsideration of production and consumption—namely, a "Great Food Transformation" (GFT).

On the supply side, three changes are necessary.

- *Halve animal-based food production and increase plant-based production.* First, it is necessary to couple a sizeable reduction in animal-based food production with a swift increase of plant-based food production. Fundamentally, this implies a substantial reduction in global livestock (now counted in excess of 77 billion against a global human population of 7.6 billion). Specifically, global production of red meat (especially beef, sheep) and dairy—which requires the farming of cows and sheep—will need to be cut by about 50 percent, through substitution of proteins supplied by plants (IPCC, 2019).[7] Urgent action in the top three beef (United States, Brazil, European Union) and dairy (United States, India, China) producers is particularly important.

Substituting half of the nutrition we source from animals with nutrition sourced from plants is necessary on two grounds. Number one: farmed animals consume more food than they produce in terms of both calories and proteins, since most of the caloric energy animals consume is used to fuel their metabolism and to form bones, cartilage, feathers, fluids, and other non-edible parts. Estimated Feed Conversion Ratios (FCRs)[8] measuring the amount of feed/crops needed to produce a unit of edible meat indicate that all animals are inefficient producers of human nutrition, an inefficiency that depends on animal species. For cows they are estimated at 25:1, for pigs at 9.4:1, and for chicken at 4.5:1 (Smil, 2008). It follows that diets rich in red meat and dairy, like the "Western diet," are incompatible with a growing population—animal-based diets require many more crops than feeding people directly with plant-based diets and it is simply impossible to feed the whole future world population a diet containing meat and dairy given the planet's resources of land, water, soil and air.

Halving meat and dairy production would free vast amounts of land to source plant-based proteins and nutrients for the world growing population, as well as free room for environmentally-sustainable forestry, primarily through preservation or restoration of natural landscapes which promise enormous gains in terms of carbon capture but also through afforestation or reforestation. Number two: animals that are more inefficient at turning crops into protein and calories—like cows and sheep—are also heavier GHG direct and indirect emitters, reflecting the fact that feeding them requires more resources, including land from deforestation (IPCC, 2019). With so much land currently being used to raise this livestock or the food to feed them, it is a constant challenge to find adequate pastureland to meet demand. This means that producers have had to create pastures where there were not any originally, with world pristine forests being a popular choice. Currently, 260 million acres (and counting) of U.S. forests have been clear-cut to create land used to produce livestock feed, and 80 percent of the deforestation in the Amazon rainforest is attributed to beef production.

- *Shift to organic, regenerative farming.* Second, we need a large-scale shift away from conventional monoculture agriculture toward practices that support biodiversity, such as organic and mixed crop-livestock farming, sustainable soil management, and ecosystem restoration. As the FAO has stated (2018): “Needed are innovative systems that protect and enhance the natural resource base, while increasing productivity, implying a transformative process towards ‘holistic’ approaches, such as agro-ecology, agro-forestry, climate-smart agriculture and conservation agriculture, which also build upon indigenous and traditional knowledge. Technological improvements, along with drastic cuts in economy-wide and agricultural fossil fuel use, would help address climate change and the intensification of natural hazards, which affect all ecosystems and every aspect of human life.” Such a shift would contain and potentially reverse some of the hazardous dynamics that have emerged over the past few decades as a result of the spread of conventional agricultural methods. Denmark and the Netherlands were among the first countries to announce ambitious plans to transition to organics, while Austria is the present leader with 22 percent of the utilized agricultural area (UAA) engaged in organic farming in 2016. Restoring soils with regenerative practices (e.g., planting cover crops and perennials and eliminating monocultures) could lock up as much as 60 tons of carbon in soil and vegetation per acre, thus reducing levels of carbon dioxide in the atmosphere. Leading soil experts have calculated that a mere 2 percent increase in the carbon content of the planet’s soils could offset 100 percent of all greenhouse gas emissions (Lal, 2018).

Today, conventional agriculture is by far the predominant method of production in advanced and large emerging market countries. However, sustainable agriculture, usually described as “organic farming”, i.e. the use of scientific farming techniques that protect the environment, public health, human communities, and animal welfare, is slowly emerging in advanced and large emerging market economies alike (Ikerd, 2017).

Results from 30-year side-by-side comparisons of conventional and organic farming methods at the Rodale Institute in Pennsylvania showed that, contrary to conventional wisdom, organic farming can outperform conventional farming in every measure. The Rodale trials show that after a three-year transition period, organic yields equaled conventional yields. What is more, the study showed that organic crops were more resilient. Organic corn yields were 31 percent higher than conventional crops in years of drought, for example. Drought-year yields for organic crops are remarkable when compared to genetically modified (GM) "drought tolerant" varieties, which showed increases of only 6.7 percent to 13.3 percent over conventional (non-drought resistant) varieties. This is of particular interest considering that climate change is likely to bring drier conditions in many areas. These findings were corroborated by a new meta-analysis that reviewed yield comparisons from 115 studies—more than three times the amount of any previous analysis published (Ponisio et al., 2015). The study reported that organic farms that practice rotational or multi-cropping had negligible yield gaps—between eight and nine percent relative to conventional yields, and these gaps inverted at times of drought or excessive precipitation.

Looking at farmers' income, multiple recent studies suggest that non-conventional agriculture is 3-6 times more profitable than conventional agriculture even when receiving smaller or no subsidies relative to conventional farming (Crowder and Reganold, 2015; Rodale Institute, 2015).[9] Part of the competitive edge of non-conventional farming comes from the premium price—driven by consumer demand—that organic farmers can get for their products. Several comparative studies find that, even when profits are adjusted for 50 per cent of the current organic premium, organic agriculture still comes out ahead of conventional agriculture because of a series of additional advantages. To begin with, organic agriculture not just delivers better quality but produces similar or larger quantities than conventional agriculture, since it is more resilient to climate volatility. Second, organic agriculture has lower input costs than conventional agriculture, being less dependent on fossil fuels as well as on expensive inputs like pesticides or herbicides, water, and associated annual loans. This makes organic agriculture less vulnerable to financial market fluctuations even in the face of more field operations (Delbridge et al., 2011). Third, organic agriculture is a low-waste system and uses less land for the same profit. Fourth, in contrast to conventional agriculture, farms engaging in organic agriculture also accumulate "natural capital"—an array of ecosystem services and resources that increase the value of the farmland. These include soil enrichment, particularly soil's ability to sequester considerable amounts of carbon; greater soil water retention, which can improve yields by 40 percent during droughts, providing a natural insurance against climate volatility; biodiversity, which means a succession of blooms that can feed insect populations (and provide them with habitat) year-round. These beneficial insects help to keep down populations of harmful insects, reducing or eliminating the need for pesticides, and providing pollination services to increase harvest yields; as well as genetic diversity on organic vegetable and seed farms, which acts as a well-endowed gene bank for potential new varieties that will be resilient against future environmental changes, insect populations, and diseases.

These benefits allow farmers to at least partially overcome the financial constraints and lessen the initial economic risks of venturing in non-conventional methods of production, especially in the years when the new organic crops or animal breeds are established (Cernansky, 2019).

In 2016, the global organic farming market accounted for around 58 million hectares of organic agricultural farmland, with the United States accounting for nearly half the global market—followed by Europe (nearly a third) and China (6 percent) (Lernoud and Willer, 2018). Nearly 180 countries reported organic acres in 2016—yet a mere 1.2 percent of global agricultural land. However, production is rising in response to the sharp increase in organic consumption. Demand consistently exceeds supply in most markets as organic products have shifted from being a lifestyle choice for a small segment of consumers to being purchased at least occasionally by many. Consumers are responding to organic's nutritional health benefits, non-toxicity, and tastiness as well as socio-ecological benefits, including the low environmental footprint and greater attentiveness for animal welfare.[10]

On the supply side, organic premia and additional economic advantages have attracted considerable capital over the past decade or so and, as a result, the organic market is going through a simultaneous process of expansion and concentration. Globally, the market, which is about ½ US-owned and operated, is dominated by 15-20 top players and is seeing growing collaboration between farmers and top food brands (Cernansky, 2019). The market is expected to triple in value by 2024, to around $320 billion, reflecting a global average growth rate of nearly 15 percent per year between 2017 and 2024 (ZMR, 2017; Technavio, 2019). Some market analysis predicts even faster growth (Allied Market Research, 2018). Both Asia-Pacific and Europe are expected to show significant market growth, owing to expanding organic agricultural land in these regions.

Similarly to organic farming on land, regenerative ocean farming can both sequester carbon and restore ecosystems. Batini, Johnson and Smith (2020) look in more detail at the benefits and policy options to foster regenerative ocean farming in Chapter 4 of this book.

- *Rewild, reforest and afforest land*. Third, the creation of forest carbon funds, for the purpose of planting forests and reducing deforestation, will be an integral part of limiting climate change since intact forests sequester twice as much carbon as planted monocultures. A proposed companion pact to the Paris Agreement—a Global Deal for Nature—targets 30 percent of earth to be formally protected and an additional 20 percent designated as climate stabilization areas, by 2030, to hold global temperature increases below 1.5°C. In Chapter 8 of this book, Batini (2020) looks at challenges in land and forest conservation and proposes a palette of actionable policies to redress them in line with recommendations in the Global Deal for Nature.

If sizeable and consistent, these three changes combined can slash emissions, boost carbon sequestration from arable soil, release land for crops and forests, halt biodiversity and pollinator loss, and restore global freshwater resources.

Changes in supply and land use must be accompanied by a shift in diets toward more and more diverse plant-based foods. In Chapter 5 of this book, Batini and Fontana (2020) discuss challenges, targets and policies to move to more plant-based diets globally.

Benefits of Greening Food Supply

Economic Benefits

On the macroeconomic front, a well-designed transition to a sustainable agri-food system promises several tangible gains including an increase in agricultural production and value-added, more numerous farm and food industry jobs, and substantial trade gains relative to a business-as-usual scenario.

Calculations of the economic benefits of the Great Food Transformation are likely to vary depending on each country's level and type of agricultural production, income level, and share of agricultural employment. Simulation for a representative country where industrial farming is the norm, however, can give a broad sense of potential economic benefits. Specifically, simulations conducted for France looked at the effect of a series of changes by 2050: gradual elimination of all synthetic inputs to production and their total replacement with agro-ecological methods; a full shift in the sector's use of energy to renewables; a reduction in the herd of cows (against unchanged pasture land) accompanied by an expansion of smaller-sized livestock herds, notably ovine; and an expansion of agro-forestry production. These changes could: (i) quadruple agricultural non-food production, while maintaining current levels of primary production; (ii) raise the sector's value added by 10 percent; (iii) avert the projected deterioration of the sector's trade balance by increasing cereal exports to the Mediterranean region and the Middle East, halving exports of fodder crops to Europe, and eliminating imports of soya and France's trade deficit from commerce in forest products; (iv) increase agricultural jobs by 7–11 percent at current productivity growth levels, and by more for lower future productivity levels; (v) double the stock of agro-ecological infrastructure, with multiplicative growth effects on the rest of the economy (Solagro, 2016; and Batini, 2019a).

Similarly, Ikerd (2018) compared the community impacts of conventional, industrial agriculture in the US, using data from Michigan, versus those of sustainable farmers who market directly to local customers. These calculations suggest that the sustainable farmer contributes about four times as much to the local economy as the industrial farm. These are just the first-round economic impacts. The multiplication effect of the combined direct and indirect effects of local sustainable farming is estimated to beat the economic impact of conventional (industrial) farming 5:1; the effects on employment are estimated to be even larger and in the range of 10:1 (Ikerd, 2018). It is likely that other advanced economies would enjoy comparable economic gains.

In emerging and developing economies, the economic advantages of making agriculture and fishing sustainable domestically promise to be larger still, since agriculture in these economies still employs about 1 billion people (ILO, 2019) and, absent the Great Food Transformation, these jobs risk being lost permanently if the sector were to follow the same path as advanced economies. Critically, a more localized, sustainable, and profitable food supply in these countries would reduce dependence on imports from other nations, increase market competition internationally, and boost their sources of income at home (Hanley, 2014; Boltvinik and Mann, 2016). If the price of agricultural goods was to become gradually less dependent from the price of fertilizers food commodity prices would be less influenced by other highly-volatile commodity prices, sheltering the income of poorer countries that depends more heavily on agricultural produce (IMF, 2008).[11]

Indeed, the 2019 IPCC Report on Climate Change and Land Use shows that "sustainable land management, [and] […] reducing and reversing land degradation, at scales from individual farms to entire watersheds, can provide cost effective, immediate, and long-term benefits to communities and support several Sustainable Development Goals (SDGs) with co-benefits for adaptation and mitigation" (IPCC, 2019).

Beyond macroeconomic gains, a shift to more plant-based food production promises investors worldwide lower financial risks and higher financial returns on investment. In recent years, fossil-fuel-free investing has become an important response from investors of all sizes to growing awareness of the need to bring the fossil-fuel age to a close. This trend, together with the lower demand of fossil fuels as a response to climate change, is leading to a drop in energy prices, meaning that only the lowest-cost projects will deliver an economic return. This implies that some fossil fuel extracting and refining projects risk becoming stranded assets even before they are built.[12] In a similar vein, as people take action to address the climate crisis, concerns about the climate impacts of food systems and the benefits of a plant-based diet are also increasingly coming to the fore, affecting risks and returns of the agri-food sector, as protein diversification is increasingly recognized by institutional and individual investors as "SRI" (Socially-Responsible Investing), "impact investing," "green investing," or "ESG" (Environmental, Social, and Governance).

Measures of the impact of intensive livestock and fish farming are being developed to analyze the largest global meat, dairy and aquaculture producers by combining nine environmental, social, and governance (ESG) risk factors with the Sustainable Development Goals (SDGs).[13] The Coller FAIRR Index, for example, shows promising potential return from investing in alternative proteins: specifically the index classifies 2/3 of industrial meat, dairy, and aquaculture companies as 'high risk' on overall management of sustainability; 3/4 of companies as 'high risk' on antibiotics management; while only 5/60 companies in the index are prepared to capitalize on opportunities in the rapidly growing alternative (non-meat or dairy) proteins sector (FAIRR, 2018). The index also unveils that over 3/4 of companies in the index showed poor or no reporting on greenhouse gas emissions; that only around a quarter of companies specifically referenced their management of animal waste; and that only 1/3 of companies report on water use from their operations—a serious concern considering that agriculture accounts for 92 percent of global freshwater use, nearly one-third of which is for animal agriculture.

ESG scores also illustrate growing investor demand for sustainable food. Plant-based investing totaled US$8.7 trillion in assets under professional management in the United States alone as of 2016, according to the Forum for Sustainable and Responsible Investing (FSRI, 2018. See also Green America's Green Business Network, 2019). Multiple financial instruments are available for plant-based investing. On the equity side, custom stock mixes or exchange traded funds seemed preferred options, but some investors have resorted to mutual funds managed by leaders in animal or cruelty-free investing like, primarily, portfolio managers who have signed onto the FAIRR initiative.[14] In terms of returns, investing using ESG ratings has been shown to reduce risk and offer tangible financial advantages relative to unscreened investments (CSSP-South Pole Carbon Asset Management, 2016; Gregory, 2017; In et al, 2019; Gorte, 2019; Bloomberg Intelligence, 2019), promising an increase in investment bias toward those products.

Environmental Benefits

The 2019 IPCC report estimates that changes in food production, combined with agroforestry, can reduce global greenhouse gas emissions up to 26 percent (9.6 $GtCO_2eq\ yr^{-1}$) by 2050. Future land use depends, in some measure, on the desired climate outcome and the portfolio of policies enacted.

In fact, the report finds that all pathways capable of containing global warming to 1.5ºC or well below 2°C require land-based mitigation and land-use change, with most including different combinations of reforestation, afforestation, reduced deforestation, and bioenergy. A small number of modelled pathways achieve 1.5ºC with reduced land conversion and thus reduced consequences for desertification, land degradation, and food security (IPCC, 2019).

Changes in food production would be also key in helping eliminate price and quantity distortions, and in particular, contribute to lowering the price of plant-based foods. This would help make sustainable diets, like the Eat-Lancet “planetary diet” discussed in Batini and Fontana (2020), affordable for all.[15]

Aside from enabling us to dramatically slash greenhouse gas emissions, sustainable farming produces crops and raises animals without relying on chemical pesticides, synthetic fertilizers, genetically modified seeds, or practices that degrade soil, water, or other natural resources. By growing a variety of plants and using techniques such as crop rotation, intercropping, conservation tillage, biological control, and pasture-based livestock husbandry, sustainable farms protect biodiversity and foster healthy ecosystems, addressing all the planetary challenges posed by industrial agriculture.

Policies to Green Food Supply

Well-targeted economic, financial, and trade policies, as well as structural reforms, can go a long way toward delivering these goals. Specifically, three sets of policy levers can be deployed to feed growing populations in a sustainable and healthy way.

Fiscal Policy

On the supply side, fiscal measures to shift supply may include adjustments to both taxes and subsidies.

- *Taxes.* Tax adjustments should focus on calibrating direct and indirect taxes and social security contributions (SSC) to agri-food production and agri-food sales based on the level of externalities these generate. For example, net profits from conventional farming should be taxed more than net profits from organic farming, as the former's externalities are several orders of magnitude larger than the latter.

To this end, on the tax and payroll contribution front, several fiscal options are at hand.[16] Building on existing differentials in the way various agricultural products, farms are taxed and by differences in income and payroll taxes between agriculture and othe economic sectors, , it is possible to modify further the way agriculture is taxed to penalize more the least sustainable agricultural activities.[17] Accounting for supply elasticities to fiscal costs, these modifications can be devised to be cumulatively fiscally-neutral in the new production equilibrium.

Similar to the approach taken to promote clean energy, changing the tax structure can engineer a targeted shift in: (i) the type of farm animals bred (for example, by reducing taxes on income generated by rearing and selling more sustainable animals like poultry relative to the taxation levied on breeding bovines, which are considerably less sustainable);[18] (ii) the way farm animals are bred (for example, by reducing the relative taxation on income from selling animals reared organically and with longer pasture exposure); (iii) the type of crops farmed (for example, by reducing taxes on income generated producing legumes, pulses, and cereals relative to that on income from producing less sustainable produces, like potatoes and sugar)[19]; and (iv) the type of farming practiced, (promoting agro-ecology and regenerative farming operated through poly-functional farms with a higher labor-to-acre ratio vis-á-vis large, monoculture, highly-mechanized farms.[20] Additionally, increases in estate taxes should be considered to prevent accumulation of inter-generational landed wealth in countries where land ownership is concentrated.

A land value tax (a tax levied on the value of unimproved land) has been proposed as a potential solution to a variety of problems, from business tax avoidance to high house prices. In theory, it is the only non-distortionary tax—income tax reduces the incentive to work, corporation tax reduces the incentive to invest in business, stamp duty reduces the incentive to sell property etc., whereas land is not affected in size whether it is taxed or not. A land value tax can also help reduce land prices because economic factors other than profitability of agriculture determine land values, including capitalization of single-farm payments and business roll-over tax relief. While land overvaluation is advantageous for investors and speculators (see Batini, 2019b), it complicates entry into farming and the profitability of farming businesses because prices become too removed from the potential profitability of the business.

- *Subsidies*. Currently, in many countries, large amounts of taxpayers' money are spent on subsidies that encourage otherwise unprofitable, unsustainable meat and dairy production predicated on the systematic inhumane treatment of farmed animals, as well as growing monoculture commodity crops for animal feed. (According to the latest OECD estimates, subsidies to agriculture in 53 OECD member countries amounted to US$705 billion per year—or over US$1.3 million per minute. In the 2016-18 period, this amount is comparable to Switzerland's 2019 GDP (Switzerland GDP ranks 20th in the world). The OECD estimates that only 1 percent of these subsidies are used to benefit the environment, while most go to meat and dairy production either directly or indirectly. Over half of these subsidies are distortive, a percentage that has slowly fallen over the years from higher peaks in the late 1980s when about 90 percent of all estimates is estimated to have been distortive. Even more taxpayers' money then goes to fixing the resulting problems: water and air pollution, animal-borne pandemics, anti-microbial resistances, and the impacts of unhealthy diets. Subsidies for unsustainable farming in advanced economies also discourage private investment in agriculture in developing economies, leaving their consumers dependent on imported food and exposed to volatile international food prices.

Like in the case of taxes, subsidies to agri-food production should be recalibrated to better reflect the level of externalities its various activities generate. For example, subsidies currently destined for unsustainable farms should be redirected toward sustainable ones producing plant-based protein, innovation on alternative proteins, and smart farming technologies. In developing economies, replacing production subsidies with ecological payments to sustainable farmers could reorient industrial agriculture, adding to the climate mitigation potential, while reducing negative impacts on farm incomes. Focusing efforts on women farmers and indigenous people and enhancing local and community collective action is particularly effective (Cook et al, 2019). Chapter IV discusses these issues in more detail.

- *Public investment*. Climate-smart technologies and practices are emerging, including methods to expand biomass energy production from crop and food wastes, manure management, renewable energy-based farming systems, solar- or wind-powered water pumping, drip irrigation, innovative greenhouse technologies, and efficient field machinery. Still critically needed are additional public-private early warning systems for weather, crop yields, and seasonal climate events and public support for innovation in sustainable agricultural technology.

Structural Reforms

In addition to the fiscal measures discussed above, structural reforms are necessary to fix regulatory failures. Among many possible others, these include:

- *Regulatory changes* aimed at simplifying the transition to a new global food system are key. Main levers include: (i) limit to the acreage per county or region that can be dedicated to monoculture crops in relation to polyculture and/or rotating crops; (ii) impose cover cropping and regulate tilling; (iii) step up environmental regulation to prohibit industrial farming activities that cause damage to air, land, water and soil by providing clear environmental thresholds to nitrogen, ammonia and phosphorous in water, land and air; (iv) ban concentrated animal feeding operations by introducing strict limits to the number of livestock per farm and per acre; (v) limit the use of antibiotics, hormones, pesticides, chemicals, and genetic manipulation of live beings including plants; (vi) impose automatic fines for inhumane livestock conditions, defined by strict scientific criteria; (vii) lessen the regulatory burden associated with the use of land for agricultural purposes (e.g. by introducing changes to zoning regulations); and (viii) reduce the barriers to converting to organic agriculture (Batini, 2019b).[21] These changes should be accompanied by regulatory efforts to (viii) enhance the compatibility and coordination of agricultural development and biodiversity conservation policies, (ix) legislation that protects the rights of farming communities as conservators of biodiversity, like those of indigenous populations of pristine ecosystems, like the Amazons (see Scherr and McNeely, 2008).

- *Land reforms* to foster agro-ecological food production. Land is not the same as other goods and therefore needs to be treated not as a commodity but as a common asset. Measures to lengthen tenancies and ensure availability of land can support projects that are sustainable and productive, create livelihoods, enhance the environment, and involve local people in making decisions about the places they care about. Land reforms should create (where missing) publicly available, comprehensive, and transparent land registries. This would enable farmers to identify and make contact with landowners, and identify opportunities since, typically, land is only required to be registered when it is bought or sold. This means large historic holdings, where little may change hands in centuries—are not covered.

- *Public sponsoring* of food-industry businesses initiatives to research, test, and scale up new strategies that propose and guide healthy and sustainable consumer choices in line with recommendations, for example, of the World Resource Institute's Better-Buying Lab. *Incentives* through conceptualization, education, training and dedicated administrative simplification for all voluntary greening schemes.

The above policies should be reinforced by supply-side structural reforms, such as:

- *Labor market measures* to promote farming jobs and small agricultural enterprises;
- *Training and apprenticeship programs* in sustainable and organic farming and small agricultural business administration.

Financial Policies

A number of financial constraints make it difficult to switch to organic farming. First, relative to conventional farming, organic farming requires both different equipment and other costly up-front investments and more labor, mainly to tackle weeds. Second, during the initial years, organic farming may produce reduced yields. Third, most nationally-recognized organic certifications require crop rotation, which limits the crops farmers can produce in a given year, whereas a conventional producer can select a crop that appears to be most profitable that year and plant it. Likewise, agricultural infrastructure—for example grain storage facilities and transportation networks—is designed for conventional crops; organic farmers need to tap into a different market structure. At the same time, funding for organic research pales in comparison to conventional support, which means organic farmers have fewer tools available to them, such as improved crop varieties and strategies for battling weeds or disease, as well as fewer experts to consult.[22] Finally, the transition period to organic farming itself can be a money-losing proposition. Farmers need to keep their land free of most chemicals for a full three years before they can be certified as organic which implies that during the transition farmers are basically farming organically but cannot get the premium.

To help farmers make the switch, in recent years some large organic companies/brands have launched “certified transitional” initiatives, which formally certify when a farmer is undergoing a shift to organic methods and secures them at least a limited premium to help get through those initial years (Cernansky, 2019). More, however, needs to be done. Helping farmers overcome these hurdles will require transitional technical and financial assistance, including direct loans, guarantee schemes, crop insurance, and measures to improve land and market access (see Batini, 2019b). Currently a mere 1.2 percent of global agricultural land is farmed organically, a figure expected to reach only 3.2 percent by 2024 under current policies.

Also, on the financial side, changes to prudential regulation to properly account for the financial risks institutions take when they lend to non-sustainable agri-food firms would provide essential support to a Great Food Transformation. A bolder approach to investment of public funds in assets associated with sustainable land use and steps to expand green and sustainable bond markets could help also fund the transition (Batini, 2019b).

Countries Leading the Transformation

The Netherlands’ 2030 “Plant Protection Vision”

Despite being a small and densely populated country, the Netherlands is the second-largest exporter of agriculture in the world, after the United States, and is leading the way in agricultural innovation. In 2017, the Netherlands exported US$111 billion worth of agricultural goods, including US$10 billion of flowers and US$7.4 billion of vegetables. Dutch farmers are pioneering ways to produce higher yields because both land and labor in their country are expensive, so they have to be more efficient than others to compete. And that competition drives innovation and technology.

Examples of sustainable, innovative agriculture adopted by small, family-run businesses, include using geothermal energy to heat greenhouses, and growing plants in a hydroponic vertical system to use less water. At one of the top-exporting farms, for example, the tomatoes are grown in small bags of rock wool substrate, made from spinning together molten basaltic rock into fine fibers, which contains nutrients and allows the plants to soak up water even when moisture levels are low. No pesticides are used and the farm pipes waste CO_2 into the greenhouses into local oil refineries, which the plants need to grow, and which reduces the carbon dioxide being released into the atmosphere. In addition, greenhouses have a double glass roof to conserve heat as well as LED lights, which mean the plants can keep growing through the night. All of this means that farming teams can produce higher yields of vegetables, in less space, using fewer resources—a technique known as precision farming, whereby farming leverages new techniques and innovations with minimum impact on the environment.

Currently, the Netherlands organic agricultural area measures around 48 thousand hectares and counts about 4,000 organic operators. Over the past ten years, the organic market has experienced sustained growth with top selling products including milk and dairy products (4.8 percent of all milk and dairy products sold), fresh vegetables and potatoes (3.9% of all fresh vegetables and potatoes sold), meat and meat products (2.7% of all meat and meat products sold), and bread and bakery products (3.2% of all bread and bakery products sold).

To encourage even greater levels sustainability, in 2019 the Dutch government launched a new vision for the country's agriculture, which prioritizes the protection of natural resources and the reduction of the sector's environmental impact. The "2030 Plant Protection Vision" is based on two principles: innovative plant breeding and precision or smart farming, which are both hot topics for the future of EU farming. The plan calls for a "paradigm shift" that embodies the Great Food Transformation: more resilient plants and growing methods require less pesticides use; and where pesticides remain necessary, their use should be 'smart' so as to minimize environmental emissions and assure the production of crops with negligible residues. Enhancing the natural defenses of plants is at the core of the vision, with an emphasis on the development of good, healthy soil. Wherever possible, growers should use the natural enemies of weeds and pests and strengthen the natural resources available in the immediate surroundings (functional agrobiodiversity). The plan's strategy for the elimination of pesticides rests also on the promotion of new plant breeding techniques (NPBTs), namely scientific methods for the genetic engineering of plants to enhance natural traits like drought tolerance and pest resistance.[23] Another element of the Dutch plan is mitigation of the uncertainty created by climate change through better monitoring of crops and soil to provide early warning of risks—a now widely known technique called "precision farming."

The plan buttresses other general policies for stimulating rural development and sustainable agricultural production from which organic producers can benefit. Dutch organic farmers receive support under the EU's Rural Development Program and while there is no policy or action plan at the national level, some provinces, such as Noord-Holland, do have policies to stimulate conversion to organic farming. The Ministry of Economic Affairs also provides up to a maximum of 60 percent of the funding for research into organic food and farming. The challenge for the coming years is to increase the area under production and to guarantee the organic quality of the products being traded.

Denmark's 2020 "Økologiplan"

In 2015, the Danish government announced a new strategy to double organic farming by 2020 (relative to 2007) and serve more organic food in the nation's public institutions—the world's most ambitious attempt yet to support a Great Food Transformation. The government's Ministry of Food, Agriculture and Fisheries' 67-point plan, dubbed "Økologiplan," aims to strengthen cooperation between municipalities, regions, and ministries to speed up the transition from conventional to organic production on publicly owned land. A long line of new initiatives are intended to strengthen both development of and conversion to organic farming, working with alternative ownership and operation models. Critically, besides requiring organic farming on public lands, the plan also subsidizes farmers transitioning to organic and simplifies the country's organic regulations.

Through the plan, the government has committed to including more organic items on the menu of public cafeterias, hospitals, and daycare centers, targeting more than 800,000 people who use these institutions daily. Interestingly, although the Ministry of Food, Agriculture, and Fisheries is behind the plan, other ministries have also pledged to do their part. The Defense Ministry, for example, has committed to increasing the amount of organic food served at its bases. (Approximately 1.1 million kilos of food are served in military cafeterias each year.) The Ministry of Education has also committed to strengthening young people's ecological awareness. This shift is linked to Denmark's public school reform, which includes teaching students about organic farming and production in the natural sciences. Furthermore, the plan supports research into new organic solutions; creating space for new experiments; investment in new export drivers; and information to increase the sales of Danish organics nationally and globally. The government has committed a total of 400 million kroner (US$60.8 million) to its action plan.[24]

As a result of the plan, 10.5 percent of land reserved for agriculture in Denmark was transformed into organic land by 2019, and the number of organic farmers in the country is now close to 4,000.[25] Danish consumers are now the most pro-organic consumers in the world, according to Organic Denmark, an association of companies, organic farmers, and consumers. Nearly 8 percent of all food sold in Denmark is organic, the highest percentage in Europe. And Danish organic export has risen by more than 200 percent since 2007.

Conclusion

Global food production has a massive economic, social, and environmental footprint: it is the largest industry in the world, representing 10 percent of global consumer spending, 40 percent of employment, and between 25 and 37 percent of all greenhouse-gas emissions—emissions expected to rise to 50 percent of the total by 2050, as the demand for food increases alongside the world's population. In recent decades, agri-food systems in advanced and large emerging market economies have become heavily industrialized and are now the number one contributor to climate change (with transportation a far distant contributor at 15 percent of total GHG emissions). Agri-food is also the prime cause of air, soil, water, and land degradation worldwide, and the number one cause of the terrifying pace of loss of biodiversity.

Making food systems sustainable for a growing global population is technologically possible but involves a fundamental reconsideration of production and consumption—namely, a "Great Food Transformation" (GFT). Three steps are needed: (1) halve animal-based food production and increasing proportionally plant-based production to attain a level of supply that is nutritionally adequate and healthy for the entire global population; (2) shift away from conventional farming to organic, regenerative farming; (3) rewild, reforest and afforest land saved from steps (1) and (2).

Shifting supply in this direction requires embracing a specific set of familiar macroeconomic policy levers, notably fiscal policy and structural reforms. On the fiscal front, taxes should be recalibrated to be higher on crops and animal farming that is least sustainable, and agricultural subsidies should be repurposed to support sustainable farming only. These fiscally-neutral measures should be accompanied by land reforms to: (i) raise the affordability and accessibility of land to sustainable farmers; (ii) limit land available for conventional farming and support agroecology. Alongside, (iii) labor market reforms should be implemented to promote agricultural employment and the setup of start-ups and enterprises involved in small agro-business to hasten a return to the land. Other measures include (iv) public investment in research and innovation and public sponsoring of food-industry businesses initiatives to research, test and scale up new retail strategies promoting healthy food consumption; and (v) incentives through conceptualization, education, training and dedicated administrative simplification for all voluntary greening schemes.

On the financial front, transitional technical and financial assistance, including direct loans, guarantee schemes, crop insurance, and measures to improve land and market access, should be provided to help farmers transition to organic practice. At the same time, changes to prudential regulation to properly account for financial risks of institutions that lend to non-sustainable agri-food firms would provide essential support to a Great Food Transformation. A bolder approach to investment of public funds in assets associated with sustainable land use and steps to expand green and sustainable bond markets could help fund the transition.

It is hard to overstate the environmental benefits of greening the agri-food sector. The IPCC's 2019 report indicates that by 2050, reforms of crop and livestock activities and agroforestry could mitigate up to a third of all greenhouse-gas emissions. Shifting production toward plant-based foods would also halt deforestation and enable conservation of critical ecosystems and planetary resources, securing our planet's future habitability and biological richness. On the macroeconomic front, a well-designed transition to a sustainable agri-food system promises several tangible gains including an increase in agricultural production and value-added, more numerous farm and food industry jobs, and substantial trade gains relative to a business-as-usual scenario.

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Endnotes

[1] In Chapter IV of this book, DeFries looks at challenges from agri-food supply in less-advanced economies and policies to reform it.

[2] Alternative estimates based on a more accurate attribution of GHG by other sectors to the livestock sector put this figure at51 percent of all GHGs. See Goodland and Ahnang, 2009, Foer, 2019. The key difference between the two estimates is that the larger one embeds the impact of the exponential growth in livestock production (now above 70 billion land animals per year) accompanied by large scale deforestation and forest-burning have dramatically accelerated the volatilization of soil carbon.

[3] The IPCC estimates that even if carbon emissions stopped completely right now, as the oceans catch up with the atmosphere, the Earth's temperature would rise about another 1.1F (0.6C). Scientists refer to this as "committed warming" (IPCC, 2019).

[4] Chapter V in this book discusses challenges to food systems from trends in food demand.

[5] Chapters VIII-XI in this book explain pressures of biological diversity and food security from current food systems.

[6] Chapter V and the other section in this chapter discuss these trade-offs, proposing policy solutions.

[7] Chapter V in this book explains why Western diets are also bad for human health.

[8] FCR are for crop-fed farmed animals. In other words, how much more food each animal consumes than they produce. Typical feed crops are grains and legumes: corn, soy, and wheat. These numbers are important as crop-fed, factory/conventionally-farmed animals are the norm in industrialized countries and the global growth-rate of meat is alarmingly high. Intensive (factory) farming represents the overwhelming majority (>98 percent) of meat produced in countries of the Group of Twenty.

[9] Crowder and Reganold (2015) analyzed the financial performance of organic and conventional agriculture from 40 years of studies covering 55 crops grown on five continents. When actual organic premiums were applied, organic agriculture was significantly more profitable (22–35 percent) and had higher benefit/cost ratios (20–24percent) than conventional agriculture. Although premiums were 29–32 percent, breakeven premiums necessary for organic profits to match conventional profits were only 5–7 percent, even with organic yields being 10–18percent lower. Total costs were not significantly different, but labor costs were significantly higher (7–13percent) with organic farming practices.

[10] Recent food consumption surveys reveal that, for example, in the United States over half of millennials actively try to include organic foods in their diets—a higher share than for other age groups, and that preferences for organic food are comparable across different income group levels (Gallup, 2019).

[11] For example, when the prices of agricultural products suddenly increased in 2008, in the wake of higher oil prices and speculation, overall inflation picked up in a number of emerging market and developing countries, reflecting the greater weight of rising food prices in the consumer price index (IMF, 2008), and lower-income countries found themselves trapped into a higher inflation-lower growth equilibrium with a more adverse outlook for income distribution. (Forty-four million people were driven into poverty by rising food prices in the second half of 2010).

[12] Since 2018, oil and gas companies have spent US$50bn (€45.3bn) on investment projects that undermine the Paris Agreement, with a new report from think tank Carbon Tracker warning that major companies risk wasting US$2.2trn (€1.9trn) on stranded assets by 2030.

[13] The index assesses 60 of the largest livestock and aquaculture companies, with a combined market cap of close to $300bn, on behalf of the world's largest investors.

[14] Organizations that have joined the FAIRR initiative—now representing $4.1 trillion in assets—acknowledge the risk associated with factory farming.

[15] Hirvoven et al. (2020) estimate that the most affordable EAT–Lancet diet would have costed a global median of US$2·84 per day in the reference year (2011), of which the largest share was the cost of fruits and vegetables (31·2%), followed by legumes and nuts (18·7%), meat, eggs, and fish (15·2%), and dairy (13·2%). This diet costs a small fraction of average incomes in high-income countries but is not affordable for the world's poor. It is estimated that the cost of an EAT–Lancet diet exceeded household per capita income for at least 1·58 billion people. The EAT–Lancet diet is also more expensive than the minimum cost of nutrient adequacy, on average, by a mean factor of 1·6). Among regions, diet cost as a fraction of mean daily per capita household income was lowest in North America (4·42%) and highest in sub-Saharan Africa (72·73%). Geographical variation was considerable even within regions.

[16] On the general case for, and design of, environmental taxes see Parry, and others (2014).

[17] This would be administratively practical once production has been categorized in base of externalities.

[18] In countries where imports of bovine meat are high, these differentials in taxation between bovine and other meats are better implemented on the final product (meat), but this is not the case of France. Sugar beets and citrus crops, followed by vegetables, tubers, and grains are, consume the highest level of nitrogen, phosphate, and potash fertilizer per acre of cultivation. Peas and beans require just a fraction of these fertilizers per acre, in part because they have capacity to absorb nitrogen from the air.

[19] Sugar beets and citrus crops, followed by vegetables, tubers, and grains are, consume the highest level of nitrogen, phosphate, and potash fertilizer per acre of cultivation. Peas and beans require just a fraction of these fertilizers per acre, in part because they have capacity to absorb nitrogen from the air.

[20] See Barbieri, Pellerin and Nesme (2017). Comparing conventional with smaller-scale polyculture farms in the United States, Montgomery (2018) concludes that well-managed alternative farming systems nearly always use less synthetic chemical pesticides, fertilizers, and antibiotics per unit of production than conventional farms.

[21] One of the main barriers for many small-scale farmers is not being able to live on the land, whether they are tenants or owners. Agro-ecological farming is a labor-intensive business, and the farmer is at the center of the human ecology of the farm, making agro-ecological farming from offsite scarcely viable. Living onsite with no additional accommodation or travel costs can be essential to a viable business plan during the initial few years. As a result, the key planning requirements for a new agricultural residence is the major need to be on site, which includes both functional and financial viability. In practice, many farming applicants struggle with planning permits because these do not understand the nature of agro-ecological farms and often make unrealistic assumptions about financial viability, given the low-profit nature of the whole sector (and the fact that established farmers often make money from alternative enterprises, including property letting).

[22] A US-based study of 1,800 farmers transitioning to organic agriculture pointed to mentoring and one-on-one technical assistance as both critical and hard to come by. See Cernansky, 2019.

[23] The discussion over NPBTs has taken center stage in Brussels since a European court ruled in July 2018 that organisms obtained by mutagenesis are genetically modified organisms and should, in principle, fall under the GMO directive. The agri-food industry disputes the GMO classification, saying the plants obtained through these techniques might have occurred naturally or through conventional cross-breeding techniques that mimic natural processes.

[24] Full details of the plan can be found here (in Danish):
https://mfvm.dk/fileadmin/user_upload/FVM.dk/Dokumenter/Landbrug/Indsatser/Oekologi/OekologiplanDanmark.pdf

[25] Compared to 2017, for example, an additional 34,000 hectares of land was made organic in 2018 – 280,000 hectares in total in Denmark now – and the number of organic farmers in Denmark increased by 325. With almost 79,000 hectares, the region of south Jutland has the most organic farming land, followed by west and north Jutland (both around 58,000 hectares), east Jutland (almost 30,000), and west and south Zealand (just over 25,000).